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Design and Development of Automatic Stirrup Bending Mechanism

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Abstract— In the construction of any structure major work is done by labour. In column or beam there are many horizontal and vertical rods to support the concrete, they are required to be tied together so that they give enough strength to the structure. Square or any trapezoidal shape stirrups are used to tie rod together by means of tight wires. In small construction sites workers bend stirrup using traditional way. There is no other way to make stirrup with less human effort. And for this reason automation is required which is the objective of the project presented.
It is possible to decrease construction lead time with increase of the stirrup bending rate by automation only. Here an attempt is made to design and develop an "Automated Stirrup Bending Mechanism" (ASBM) using the principles of hydraulics and electronics. Its use reduces a lot of labour cost, effort and construction lead time and production of various sizes of stirrup and accuracy increases.

Keywords— Wiper motor; Microcontroller; Proximity sensors;Pisto Cylinder arrangement; Direction Control Valve; Guide Roller; LCD Keybord.

I. INTRODUCTION

Since many years labour work has been playing an important role in construction including mixing coarse aggregate-sand-water-cement, moving sand, leveling the land, digging the foundation for base of structure, cutting rod in required length, bending the rod and pouring of concrete mix in columns and beams. Now days, due to development in technology there have been a need to reduce the labour time.

Figure 1. some problems & solution related to construction

As increases population day by day, demand of construction for built the building for living, industries, overhead bridges is continuously increases. Several problems come in to the picture when we consider human power with respect to automatic mechanism. By using conventional method it is not possible to increase construction rate and decrease lead time. So, Automation in construction system is requires.

Stirrup is nothing but a square, rectangular or trapezoidal shaped rod which is tied with the structural rod together at specific distance for strength improvement purpose.

Figure 2. Manual Stirrup bending operation

The development of small stirrup bending mechanism is an area of interest that many researches wish to explore. ASBM is a true Mechatronics employed system that combines elements of Mechanical, Electronics and Control engineering. The basic framework of the ASBM consists of a mild steel base on which a pneumatically operated piston cylinder arrangement is mounted that applies the force or the push required for bending the rod. An arrangement of feed rotors run by wiper motor serves as the automatic feed mechanism for the rods. A sensor mounted along the way senses the presence of the rod that controls whether to operate the piston or not. The sensor can be adjusted to match the length of the rod required to bend. The calculation and selection for the model is done based on 6 mm and 8 mm stirrups. For this automatic control, Arduino microcontroller and IR sensors with range up to 8 cm are used.

II. CORE COMPONENTS OF ASBM

2.1. Microcontroller

The Arduino Diecimila is a microcontroller board based on the ATmega 328. It has 14 digital input/output pins, 6 analog inputs, a 16 MHz crystal oscillator [2], a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; it is only needs to connect to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started.

2.2. Wiper motor

In ASBM, a motor is used to feed the rod into the fixture and it is controlled by Arduino controller in required time interval. Wiper motor rotates under 12V DC supply and speed achieved is nearly 70 RPM [10].

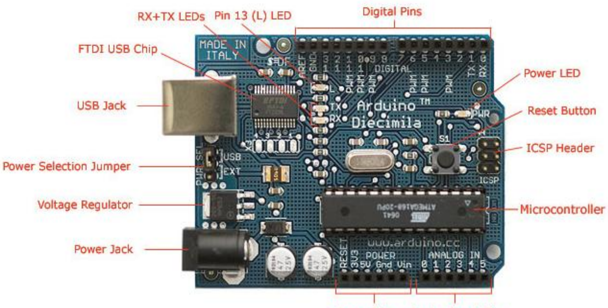


Figure 3. Arduino Controller

Figure 4. Wiper Motor

2.3. Proximity sensor

Sensor detects metallic objects without touching them. The sensor consists of an induction loop. Electric current generates a magnetic field, which collapses generating a current that falls asymptotically toward zero from its initial level when the input electricity ceases as shown in figure 5[9]. It is required to detect the presence of rod in 2-3cm vicinity and give signal to controller.

2.4. Solenoid operated DCV

Directional Control Valve (DCV) is one of the most fundamental parts in hydraulic machinery as well and pneumatic machinery. They allow fluid flow into different paths from one or more sources. They usually consist of a spool inside a cylinder which is mechanically or electrically controlled. The movement of the spool restricts or permits the flow, thus it controls the fluid flow as shown in fig. 6.

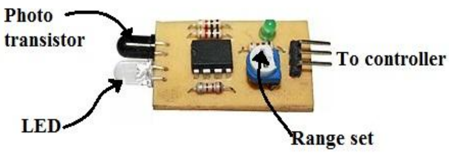


Figure 5. IR sensor

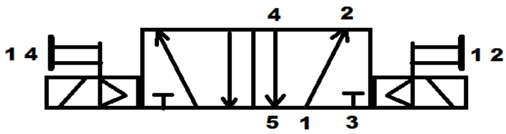


Figure 6. 5/2 DCV

2.5. Hydraulic power pack

A hydraulic power pack is a drive or transmission system that uses pressurized hydraulic fluid to drive hydraulic machinery.

2.6. Piston cylinder arrangement

In ASBM single acting spring return cylinder is used to bend the rod. Forward stroke is due to air pressure and return stroke is by automatic spring return. Stroke is completely controlled by a controller [6].

Figure 7. Piston Cylinder Arrangement

2.7. Feed rotor

Feed rotor is used to feed rod under the control of controller signals. It is operated by high torque wiper motor. Moreover it provides straight motion to rod and prevents curvature of rod.

2.8. Fixture

Fixture is use to support 6mm or 8mm rods and provides the point of bending. Fixture needs to be stronger than the rod, as all the strength is applied on the walls of the fixture. It should be strong enough for prevent bending against bending force directly acting on it.

III. CONCEPTUALIZATION AND MODELLING OF ASBM

3.1 Basic block diagram of components in ASBM

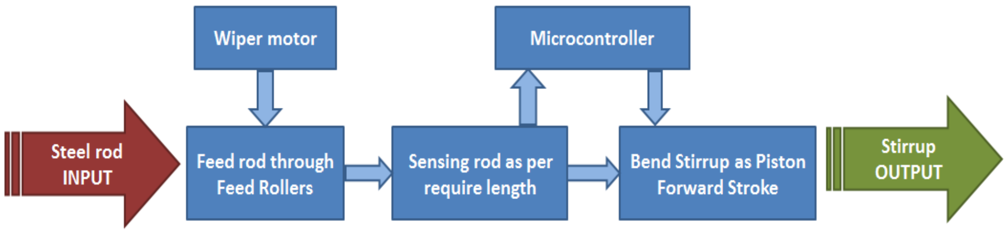


Figure 8. Block diegram of ASBM

As shown in figure, steel rod is inserted in the mechanism which feed through Feed Rollers using Wiper motor. Using proximity sensors and programmed microcontroller the piston moves forward/backward, through this process rod gets bended in form of stirrup.

3.2 3D parts of ASBM

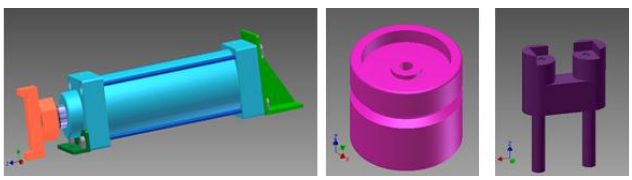


Figure 9. Assembly of piston cylinder, Feed roller, Fixture

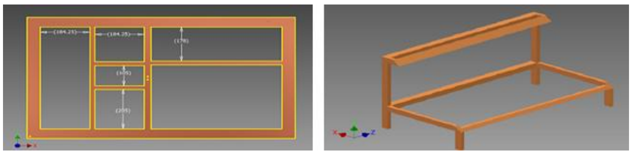


Figure 10. Frame & Base stand of ASBM

3.3 CAD prototype Model

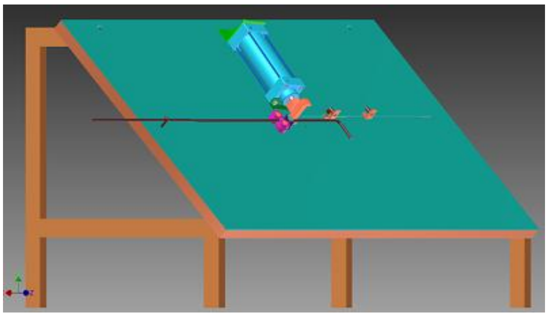


Figure 11. Assembly of Mechanism

3.4 Conceptual sequence of operations in ASBM

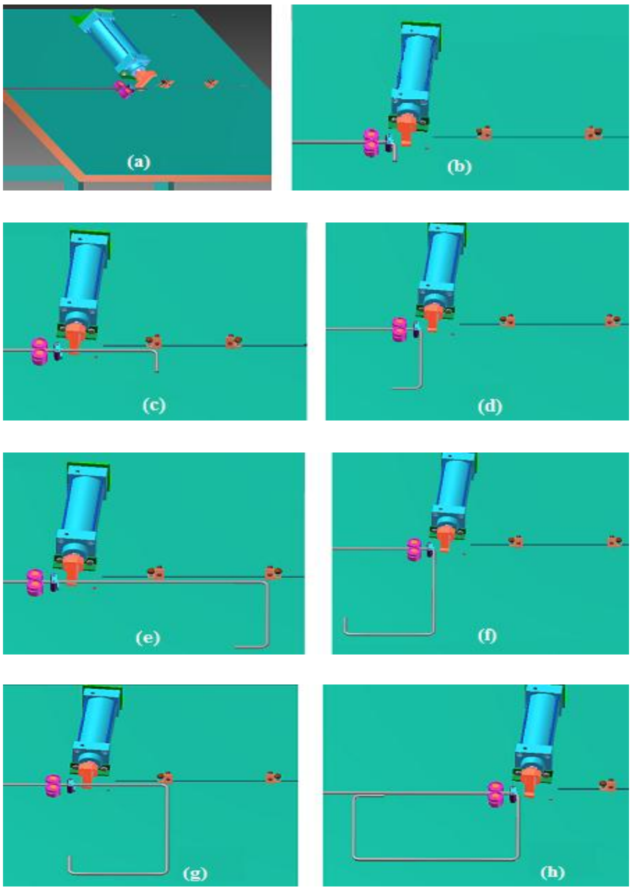


Figure 12. Sequence of operation

- Rod placed in the initial position and is about to be bent as shown in figure 12(a).
- First bending takes place; when the rod is progressed with the aid of two rollers in the forward direction by using the piston cylinder arrangement as shown in figure 12(b).
- Rod is advanced in the forward direction and stops the advancement when sensor senses the rod as shown in figure 12(c).

- Piston moves again in the forward direction and second bending takes place as shown in figure 12(d).
- Again the process continues and sensor is activated as per necessity.
- For a rectangular stirrup sensor order is 1,2,3,2,3 and for a square stirrup sensor order is 1,2,2,2,2 as shown in figures 12(e,f,g,h).
- Finally cutter does it action by cutting finished stirrup as shown in figure 12(i).

IV. MECHANICAL DESIGN & CAPACITY CALCULATION

4.1 Calculation of force for bend 6mm diameter rod

$\sigma_{yield} = 690\ N/mm^2$

$\sigma_{ultimate} = 732\ N/mm^2$

[This data was acquired from the tensile test carried out at TATA TISCON [8] in their laboratory with 8 mm diameter rod. The testing report is attached Appendix A. These rods are used for making stirrups that are used for building structures.]

$$\sigma_b = \frac{M*y}{I} \quad [4]$$

Where, $M=P*l$, $Y=d/2$, $I=\frac{\pi}{64}d^4$

$$\sigma_b = \frac{\sigma_{yield}}{fos} = \frac{690}{4}$$

$$= 172.5\ MPa$$

$$172.5 = \frac{P*7*6/2}{\frac{\pi}{64}*6^4}$$

$$\therefore P = 522.30\ N$$

4.2 Calculation of force for bend 8mm diameter rod

$\sigma_{yield} = 678\ N/mm^2$

$\sigma_{ultimate} = 722\ N/mm^2$

$$\sigma_b = \frac{M*y}{I}$$

Where, $M=P*l$, $Y=d/2$, $I=\frac{\pi}{64}d^4$

$$\sigma_b = \frac{\sigma_{yield}}{fos} = \frac{678}{4}$$

$$= 169.5\ MPa$$

$$169.5 = \frac{P*7*8/2}{\frac{\pi}{64}*8^4}$$

$$\therefore P = 946.18\ N$$

4.3 Design of Piston Cylinder

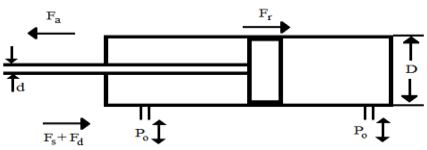


Figure 13. Design of cylinder

Let take,
Maximum force for design of cylinder, F=950 N [1]
Fluid pressure, P = 5 bar = 0.5 N/mm^2
Stroke of Piston = 100 mm
Total required force = $F + F_r$

Friction force, F_r = 3-8 % of F $\cong$ 5 % of F = 0.05* 950
= 47.5 N
$\cong$ 50 N

$\therefore$ Total Force = F + F_r
= 950 + 50
=1000 N

F=0.7854 * D^2 * P [3]

$\therefore$ 1000 = 0.7854* D^2 * 0.5

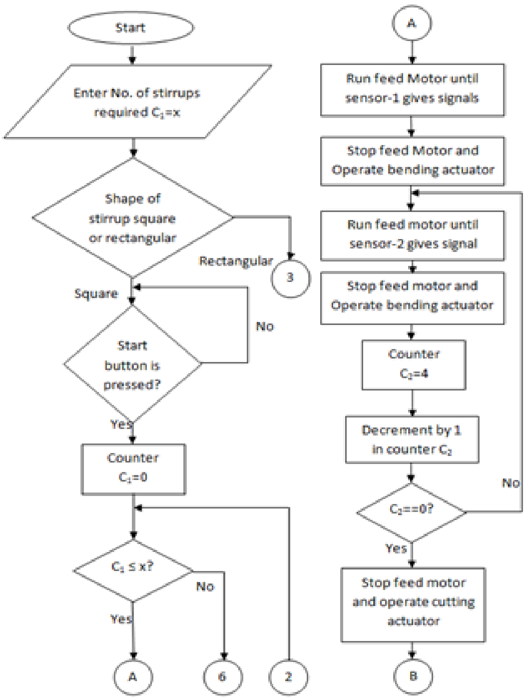
$\therefore$ Diameter of cylinder, D = 50 mm

Thus, Diameter of piston rode,
d = 0.3 to 0.8 D [6]
$\cong$ 0.5 D

$\therefore$ d = 25 mm

V. ELECTRONIC CONTROL MECHANISM

5.1 Flowchart to operate ASBM system



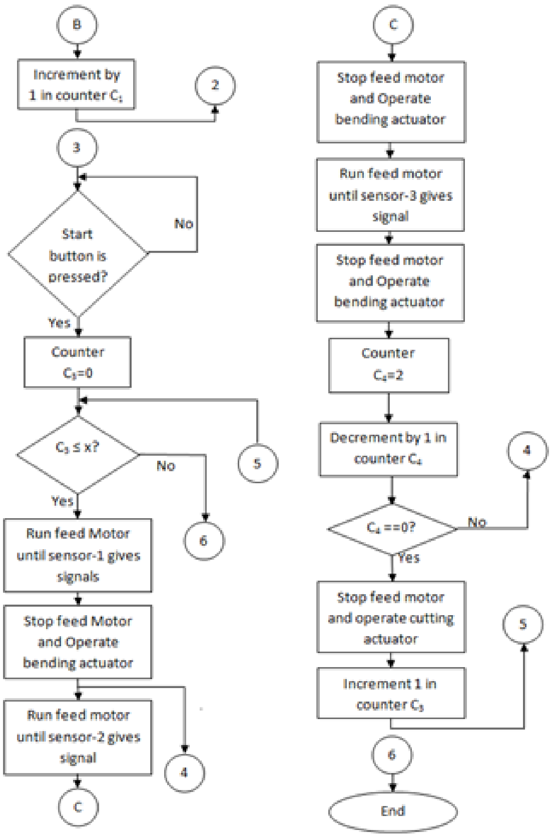


Figure 14. Flowchart to operate ASBM

5.2 Interfacing of components with Arduino control

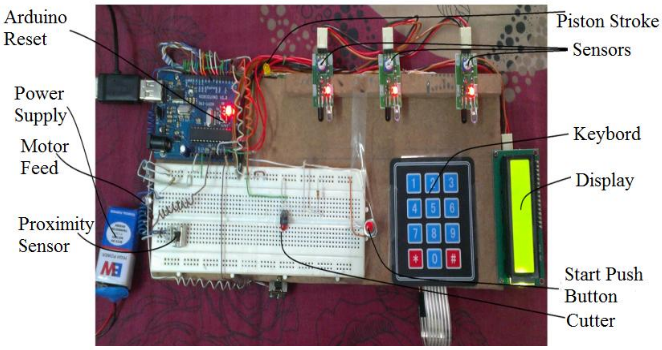


Figure 15. Interfacing of components with Arduino controller

1. When the Arduino reset is pressed, the LED glows and the 16x2 LCD display prompts the number of stirrups required. The number is fed from 4x3 numeric keyboard.
2. There after the LCD prompts whether the stirrup is to be done for a rectangle or a square and informs that pressing 1 for square and 2 for rectangle.
3. After the number is fed, the motor drives the feed rollers and the rod is pushed into the fixture.
4. When the sensor senses the rod, signals is simultaneously sent to controller for stopping the motor and gives the forward stroke of the pneumatic piston. After bending the rod at right angle the piston retracts and motor is turned back on for the feeding of rod further into the system.
5. The previous operation sequence is repeating until the one stirrup is bending out.
6. At the end of one stirrup, the cutting mechanism cut the stirrup end and display the numbers of stirrups completed on LCD.
7. This operation sequence is continuing up to initially entered number of stirrups required.

VI. TESTING AND EXPERIMENTATION ON PROTOTYPE MODEL

6.1 Actual Prototype Model

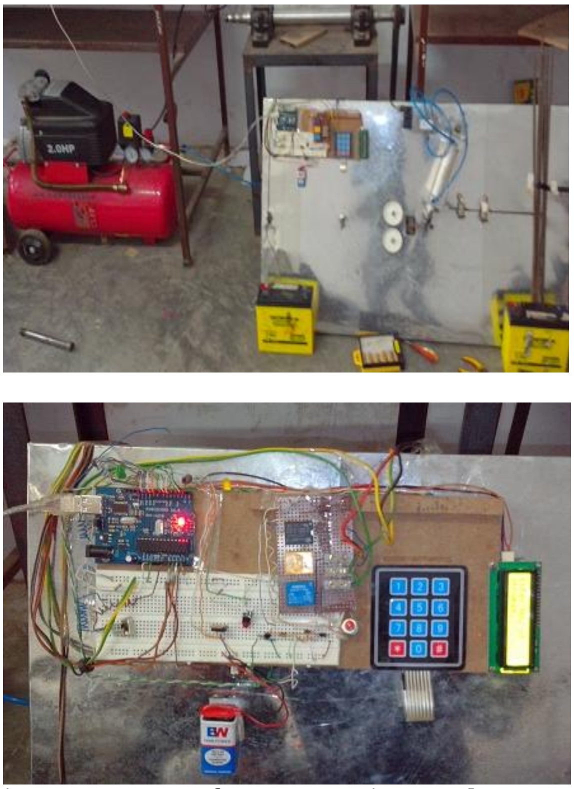


Figure 16. Setup of component in actual prototype

6.2 Sequence of opertion on prototype

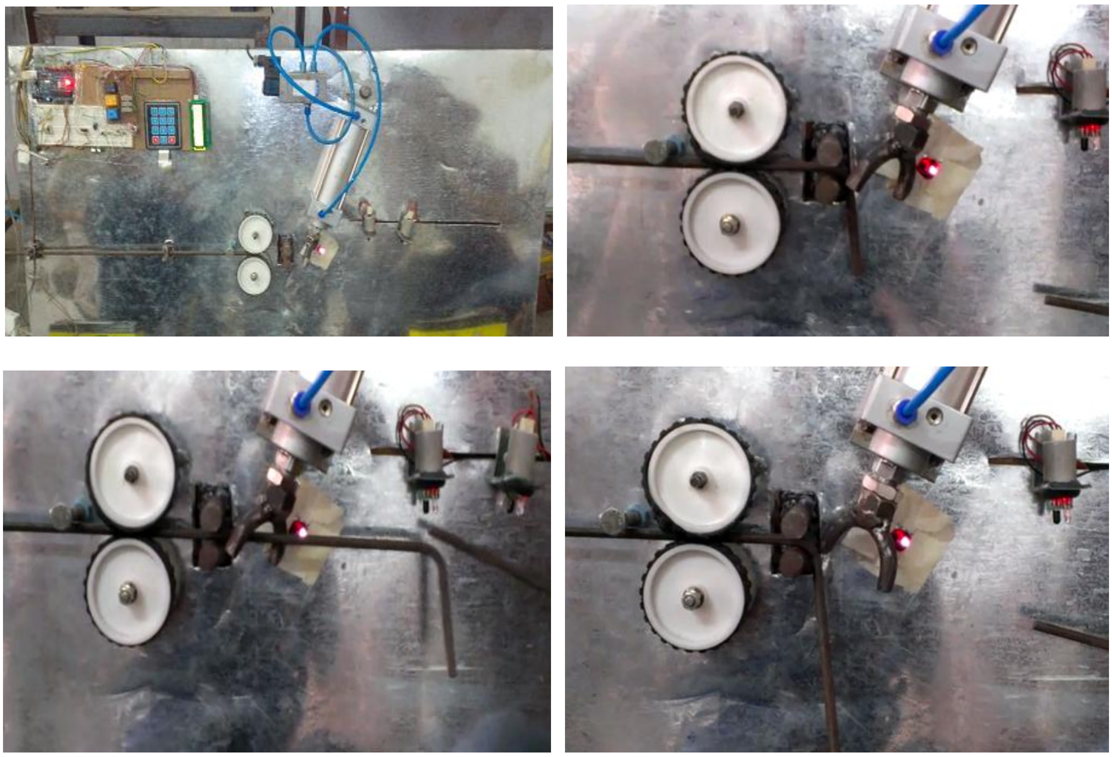


Figure 17. Sequence of operation

6.3 Basic steps to operate ASBM prototype model

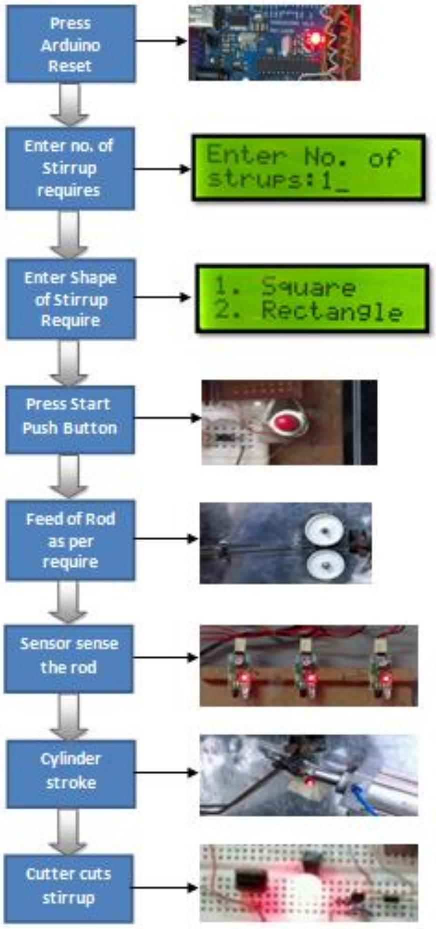


Figure 18. Steps of ASBM

VII. BREAK EVEN ANALYSES

Assume that 4 Working hours for ASBM setup,

Average Number of pieces per day= 700
Fixed cost of ASBM (F_a) =60,000 Rs.
Power consumed by 1HP Motor in Hydraulic power pack=745 watt
Power consumed by Wiper Motor =100 watt
Power consumed by Microcontroller =200 watt
Power consumed by Solenoid Valve = 30 watt
Power consumed by LCD = 25 watt
Power consumed by Other Components =100 watt
Power Loss in Components =100 watt
Total Power Consumed =1300 watt
= 1.3 KW
Total Power consumed by setup in 4 hours =1.3*4
= 5.2 KW/4 hours

Let Rs. 8 /KWh
Total Rs. = 5.2* 8
= 41.6 Rs.

Machining Cost/piece = 41.6/700
= 0.0594 Rs./stirrup
= 5.94 rupees/stirrup

Let Conventional Working hours is 8.

Fixed cost of conventional setup (F_c) = 2500 Rs.

Labour cost for bending stirrups = 350 Rs. /day

Average Number of pieces per day= 700

Labour cost per stirrup (S) =350/700= 0.5 Rs. /piece

For, Breakeven Analysis

Let X = No. of stirrups,

ASBM = Conventional

$F.C._a + V.C._a = F.C._c + V.C._c$

60000 + 0.0594*X = 2,500 + 0.5 *X

X=1,30,505 No. of stirrups

Means after bending 1,30,505 No.of stirrups the cost of machine will be recover.

Now, for breakeven period

1,30,505/700 = 187days

Let's assume, ASBM working in 20 days per month,

187/20 = 9 months and 10 days

Means after 9 months and 10 days (if working only 20 days/month) the cost of ASBM system will be recover, after that machine require only running cost which is Rs. 41.6 /day.

VIII. CONCLUSION

8.1 Conclusion

Automatic Stirrup Bending Mechanism (ASBM); using the principles of hydraulic and electronics has been developed.

ASBM system was incorporated with piston-cylinder arrangement, arrangement of feed rotors run by wiper motor to feed the rods automatically and an IR sensor to sense the presence of rod under the controlling action of microcontroller. In this mechanism, bending of the rod has been taken place by piston-cylinder arrangement while progressing the rod in the forward direction with the aid of two rollers using wiper motor. This process continues until the complete stirrup was made and the sensor is activated as per the necessity.

From break even analysis we concluded that time period for recover the cost of ASBM is nearly 9 months under some assumption.

By using ASBM system, continuous production of stirrup could be achieved and at the same time a lot of labor cost, effort and construction lead time could be reduced, from which the society will get direct benefits. ASBM is quite interesting and this would be indispensable for real time application in the construction fields.

8.2 Future of ASBM

- By addition of rod cutter and linear scale, we can improve productivity of ASBM.
- We can make it more users friendly by implementing GUI (Graphical User Interface).
- By providing some extra accessories we can use it as Hydraulic Rod Cutter using shear principal for cutting the rods of more than 8 mm diameter.

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