Development of a Model for the Number of Bends During Stirrup Making Process

S. N. Waghmare, Sagar D. Shelare, C. K. Tembhurkar, and S. B. Jawalekar

Abstract Stirrup making is a process to angling reinforcement bars at expected edges into civil engineering work. Hand-operated bar bending requires vigorous physical exercise, which is generally done in a bad ergonomic atmosphere at construction site. This could begin to prolonged musculoskeletal complications such as profound back disorder among bar benders. Current research explains a numerical model for number of bends, torque and required time to process of a stirrup making method using human fortified flywheel motor based on testing data collected, applying a method of design for experimentation. Out of the above three models, the numerical model and its analysis for a number of bend for the stirrup producing process is described here. Findings obtained by the numerical model for a number of bends positively describes the degree of interaction of multiple independent parameters for stirrup producing operation.

Keywords Stirrup · Bar bending · Human power · Sensitivity analysis

1 Introduction

The civil construction business is the other most significant businesses in India giving work to higher than 35 million people, that is nearly 16 percentage of India's serving people [1]. However, an industry creates work possibilities on a massive scale, and over 80 percent of the workers are untrained [2]. Globally, construction places are intrinsically terrible, and every year, the industry proceeds to register few most significant levels of misfortune and destructiveness among all industrial divisions [3–5]. Also, by large safety management orders and enactment in place, industrial accidents continue a pervasive, yet preventable dilemma [4, 6, 7]. In civil engineering works, bending of the bar is a method to provide angle to reinforcement bars applied

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as stirrups and support [8]. Although stirrups have been practiced since decades, various problems, such as getting the most effective geometrical stirrup pattern, are still subjects of constant investigation [3, 9, 10]. Stirrup bending is manual in most entire emerging countries, because of its cost-effectiveness [11].

At smaller civil construction site work, labors bend stirrup by the traditional approach [11]. No alternative significant method for crating the stirrup with the fewer human attempts same time; the detailed investigation of present manual stirrup-producing process shows that the process experiences different drawbacks.

In this paper, the stirrup is made from stirrup-creating setup driven by human-powered flywheel motor (HPFM) [12]. The stirrup-producing unit comprises two spur gears, and it is having 3/4 and 1/4 teeth; the gear drive is used to transmit the motion from energy unit to process unit shaft [13]. The rectangular helical spring is provided for tension and getting back the circular disk to its original position, it also provides the fixed pin which is utilized for bending the rod by 90 degrees by pressing the foot lever.

The conceptual design of stirrup producing consists of mainly pedal, sprocket, chain drive, flywheel and process unit (stirrup bending mechanism) as per Fig. 1. Fabricated setup of stirrup-producing machine is as per Fig. 2. Setup mainly consists of energy unit, transmission unit and process unit. The operator energizes the flywheel by pedaling conveniently. After storing the sufficient amount of energy, pedaling is stopped, and the energy is transferred with clutch. Five bending operations make the stirrups. The stirrup rod is first cut in predetermined length, and marking by chock then the five bending operations are performed as follows. Primarily, a smaller length of the rod is bent through inserting it into a guiding slot. By putting the rod at a centre

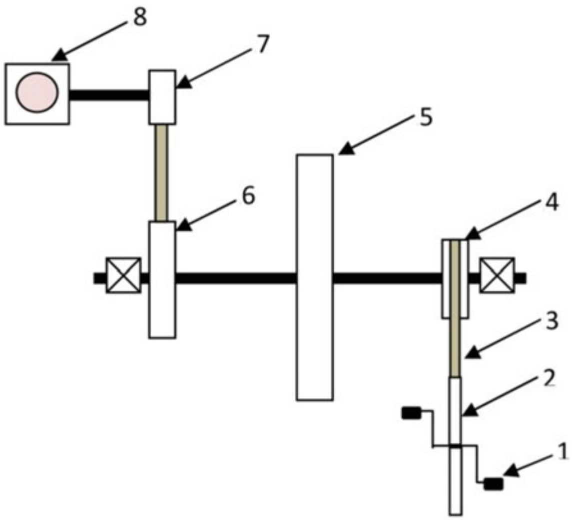


Fig. 1 Conceptual design of stirrup-producing machine. Where 1-pedal, 2-big sprocket, 3-chain drive, 4-smaller sprocket, 5-flywheel, 6-sprocket, 7-sprocket, 8-process unit (stirrup bending mechanism)

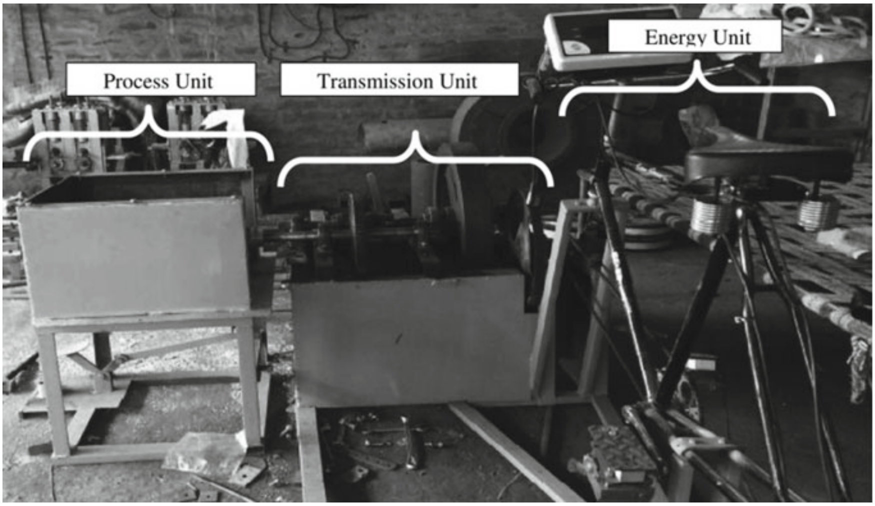


Fig. 2 Fabricated setup of stirrup producing the machine

position of the disc, operator needs to push and move the lever by foot. For the second bend, follow the same process based on the size of stirrup. Similarly third, fourth and fifth bend is made to obtain the perfect rectangular shape as per requirement.

2 Materials and Method

2.1 Experimental Model Formulation

For the model formulation, the method proposed as per Hilbert Schenck is used. This helps for deciding the minimum processing torque required, and human energy to be supplied to the system for getting bending operation for rod in minimum time [14]. By knowing this, one can form a relation for stirrup-creating method. This would be conceivable if we have a quantitative relationship among different dependent, independent parameters of the system. This relationship is the analytical model of stirrup-creating process. Notably, model of stirrup making cannot be made logically. The only alternative method is to form an innovative data-based model. In this methodology, all independent variables differ over a permissible range, a response data is gathered, and the relationship is established analytically.

In this experimentation process [15], torque (T_r), time to process (t_p) and no. of bends (n_b) are dependent or response variables whereas various independent variables are flywheel energy (E_f), angular speed (ω_f), time required to speed (t_f), stirrup diameter (d_s), stirrup size (s), bend angle (θ), stirrup hardness (H_s), pin and center distance (r), ratio of gear (G), spring stiffness (k), rotating disk diameter (d_r), rotating disk thickness (t_r), acceleration because of gravity (g), stirrup length (L_s), elasticity modulus for stirrup (E_s).

2.2 Experimental Procedure

For experimentation, the stirrup rod of 6 mm plain, 6 mm TMT holding the equivalent diameter is prepared in the machine at three separate lengths, i.e., 968.4, 1068.4 and 1220.4 mm, at four separate speeds, ranging between 300 and 600 rpm, and at three separate gear ratios 1/2, 1/3 and 1/4. Hence, two diverse materials are utilized for experimentation to control an exact use of machine. Speed need to be achieved is shown in the GUI with instrumentation system. During the experimentation process, time, torque, bend number, flywheel time to speeding, etc., are noted by a uniquely designed electronic kit, i.e., instrumentation system presented in Fig. 3 [16] (Tables 1, 2 and 3).

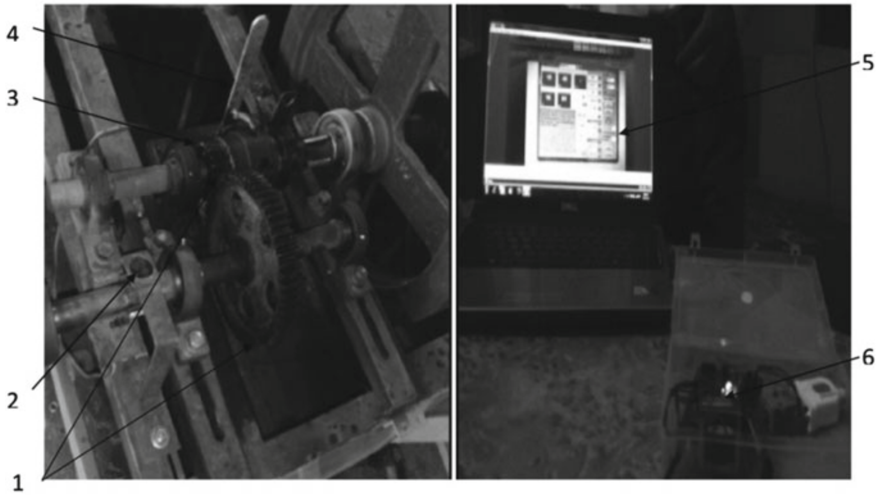


Fig. 3 Experimental arrangement and electronic kit for speed measurement with software and sensors. Where 1-speed rising gear pair, 2-sensor, 3-jaw clutch, 4-jaw clutch engaging disengaging lever, 5-instrumentation GUI showing speed, 6-electronic kit

Table 1 Plan of experimentation and observations when G.R = 0.5

S. No.	Size type	P.D	Rod type	G.R	(N)	(t_f)	(T_p)	(n_b)
1	Type-I	45.0	6-plain	0.5	300	35	56	7
2	Type-I	67.5	6-plain	0.5	300	35	63	11
3	Type-I	45.0	6-twist	0.5	300	35	91	15
4	Type-I	67.5	6-twist	0.5	300	42	91	19
5	Type-I	45.0	6-plain	0.5	400	28	32	10

Where *G.R* gear ratio, *P.D* pin distance, t_f flywheel time to speeding, N speed in rpm, T_p processing time, n_b no. of bend, Type-I-179 × 229 mm

Table 2 Plan of experimentation and observations when G.R = 0.33

S. No.	Size type	P.D	Rod type	G.R	(N)	(t_f)	(T_p)	(n_b)
1	Type-I	45.0	6-plain	0.33	300	28	42	6.5
2	Type-I	67.5	6-plain	0.33	300	21	42	10.5
3	Type-I	45.0	6-twist	0.33	300	42	91	16
4	Type-I	67.5	6-twist	0.33	300	56	77	17.5
5	Type-I	45.0	6-plain	0.33	400	28	42	9

Where *G.R* gear ratio, *P.D* pin distance, t_f flywheel time to speeding, N speed in rpm, T_p processing time, n_b no. of bend, Type-I-179 × 229 mm

Table 3 Plan of experimentation and observations when G.R = 0.25

S. No.	Size type	P.D	Rod type	G.R	(N)	(t_f)	(T_p)	(n_b)
1	Type-I	45.0	6-Plain	0.25	300	35	49	8
2	Type-I	67.5	6-Plain	0.25	300	28	63	10.5
3	Type-I	45.0	6-Twist	0.25	300	49	77	15
4	Type-I	67.5	6-Twist	0.25	300	30	80	19
5	Type-I	45.0	6-Plain	0.25	400	28	56	8

Where *GR* gear ratio, *PD* pin distance, t_f flywheel time to speeding, N speed in rpm, T_p processing time, n_b no. of bend, Type-I-179 × 229 mm

2.3 Formulation of Model by Dimensional Analysis

As per the dimensional analysis, bend number is written in function form as [17]:

$$n_b = f_2(E_f, \omega_f, t_f, d_s, s, \theta, H_s, r, G, k, d_r, t_r, g, L_s, E_s)$$

Total independent variables, $n = 15$ and no. of fundamental units, $m = 3$.
No. of Π terms $= n - m = 15 - 3 = 12$.
A mathematical model of bend number (n_b) is obtained as-

$$(n_\mathrm{b}) = f_2\left\{\left(\frac{E_\mathrm{f}}{L_\mathrm{s}^3 * E_\mathrm{s}}\right)(\omega_\mathrm{f} * t_\mathrm{f})\left(\frac{K}{L_\mathrm{s} * E_\mathrm{s}}\right)\left(\frac{H_\mathrm{s}}{E_\mathrm{s}}\right)\left(\frac{d_\mathrm{s} * r * d_\mathrm{r} * t_\mathrm{r}}{L_\mathrm{s}^4}\right)\left(\frac{S}{L_\mathrm{s}^2}\right)(\theta * G)\right\} \tag{1}$$

2.4 Design of Experiments

In this experimentation, 144 experiments were designed based on sequential classical experimental design technique, generally proposed for engineering applications, Hilbert Schenck. The basic classical plan consists of keeping all but any independent parameters constant and changing this one variable over its range. The basic reason of experiments is to find correlation in 12 independent process variables with 3 dependent responses for stirrup-creating process optimization. Simultaneously varying the all 12 independent parameters was confusing as well as complicated. Therefore, every 12 independent process variables were decreased by dimensional analysis. Buckingham π theorem was accommodated to produce dimensionless π terms for reduction of process variables [18].

3 Analysis of Model

3.1 Analysis of Model for No. of Bends

For analysis of model for dependent pi term of number of bends n_b (Fig. 4)

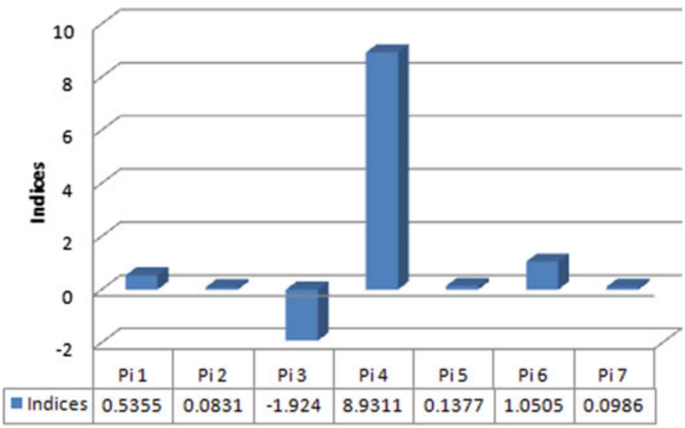


Fig. 4 Indices of dependent pie term for no. of bends

$$(n_b) = 02.59656979 \times 10^{-9} \left\{ \begin{array}{c} \left(\frac{E_f}{L_s^3 * E_s}\right)^{0.5355} (\omega_f * t_f)^{0.0831} \left(\frac{K}{L_s * E_s}\right)^{-1.9243} \left(\frac{H_s}{E_s}\right)^{8.9311} \\ \left(\frac{d_s * r * d_r * t_r}{L_s^4}\right)^{0.1377} \left(\frac{S}{L_s^2}\right)^{1-.0505} (\theta * G)^{0.0986} \end{array} \right\}$$

The reduced relationship for this pie term is given by $\pi_{02} = n_b$.

It would be seen that equation is model for a pi term containing several bends (n_b) as a response variable.

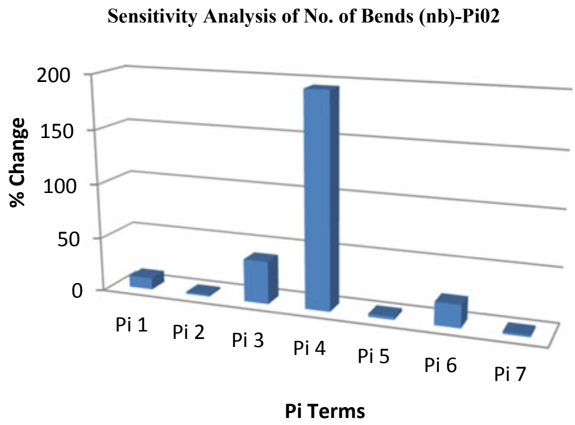
The following primary outcome can be justified from the earlier model.

(i) The absolute index of π_4 is highest, viz. 8.9311. The factor π_4 is related to properties of material; i.e., elasticity and hardness are the common growing terms. Value of this index is positive, showing the correlation within ratio for elasticity and material hardness has a sturdy impact on π_{02}, and π_{02} is immediately changing concerning π_4.
(ii) The absolute index of π_2 is lowest, viz. 0.0831. Thus, π_2, the term related to angular speed and time required speeding up of flywheel angular speed and time needed to speeding of flywheel, is the least influencing term in model. The low value of absolute index indicates the factor, angular speed and time required to speeding of flywheel demand growth.
(iii) Importance of other independent pi terms existing in model is π_1, π_5, π_6 and π_7 having an absolute index of 0.5355, 0.1377, 1.0505 and 0.0986. The indices of π_3 are negative, viz. -1.924, respectively. The positive indices are indicating the need for improvement. The negative indices are showing that π_{02} varies inversely concerning π_3.
(iv) The constant in this model is $2.59656979 \times 10^{-9}$. This value is a lesser amount than one. So, it has no magnification outcome in the importance calculated from multiplication of various terms of model.

3.2 Sensitivity Analysis

An impact of the different independent π terms has investigated through examining an indices of those different π terms in a model [19]. When series of a change of $\pm 10\%$ is added in a value for independent pi term π_1, a change of about 10.72% occurs in quantity of π_{02} (computed from the model). The change brought in a value of π_{02} because of change into quantity of the other independent pi term π_2 is only 1.667%. Similarly, variation about 39.23, 195.2, 2.761, 21.01 and 1.978% takes place because of change in values of π_3, π_4, π_5, π_6 and π_7, respectively. It is observed that the biggest change is due to pi term π_4, whereas the least change takes place due to the pi term π_2. Thus, π_4 is the most sensitive pi term, and π_2 is the least sensitive pi term. The order of the different pie terms in the ascending order of sensitivity is π_2, π_7, π_5, π_1, π_6, π_3 and π_4 (Figs. 5 and 6).

Fig. 5 Graphs illustrating sensitivity analysis, indices for Pi02



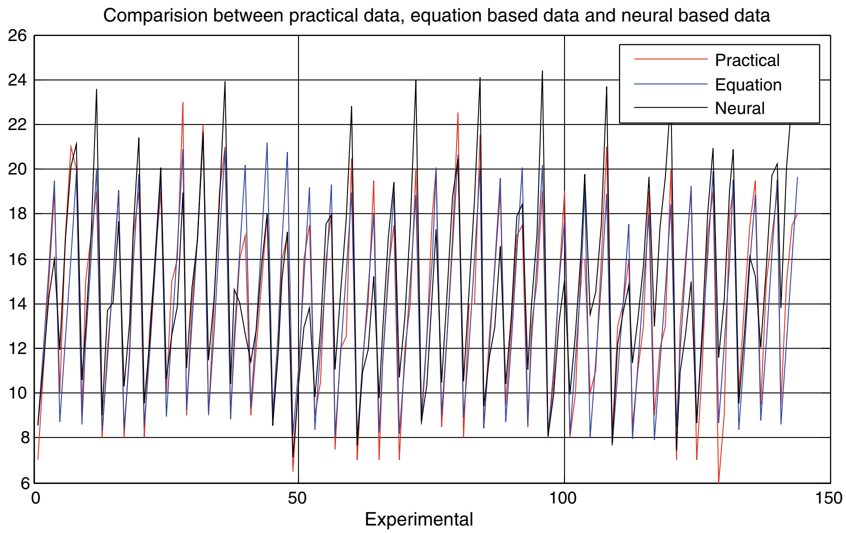


Fig. 6 Comparison of actual and computed data by ANN (for no. of bends n_b)

4 Conclusions

1. Sensitivity analysis shows stiffness of spring, rod material hardness, modulus elasticity of material is predominant over the considered independent parameters.
2. The machining attributes of stirrup-producing procedure are proved by the theory of experimentation, which was hidden in earlier cited investigation.
3. Presently most utmost, stirrups are created by the hand by the workers, and the stirrup-producing machines are operated utilizing electrical power, but the current machine uses HPFM creating a stirrup.

4. The data of stirrup-creating process is collected by performing actual experimentation. Due to this, the finding of study positively represents superiority of interplay of several independent variables. The standard error of estimate of predicted/computed dependent parameter values is found to be very low. This gives authenticity to improved analytical models and ANN.
5. The calculated choice of stirrup-forming method parameters with dimensional analysis gives practical direction to the production technicians so that they can minimize the time for optimal performance.
6. Developed setup produces intermittent energy, due to which speed obtained during operation is retarding, and a newer mechanism may be developed for constant speed.

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