

DESIGN AND ANALYSIS OF STRAIGHTENING MECHANISM FOR COMMERCIAL STEEL BARS

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Abstract -In this project the attention is focused on developing a technique to straighten commercial steel bars in an economical manner. There are machines developed by various industries to straighten drawn and coiled metal bars, but the commercial bars available in the market have differing cross section and material properties. Nowadays straightening of these commercial bars are done manually in industries by hammering process. It is a very tedious job and time consuming too. So there is an industrial necessity to automate the process. Three power driven vertical feed rolls advance bar stock through pairs of horizontal and vertical rollers in the first and second half of the machine respectively. The problems encountered during the process were the autorotation and spring back effect. The autorotation was solved by a three roller standstill locking mechanism. During the process of straightening, bars rotate around autologous axis, which cause out of the vertical of straightening surface and the straightening precision is deduced. To eliminate the autorotation of bars, parallel roller collocation scheme of cold rolled deformed bars with high speed and no scratches is presented. Based on the theory of elastoplasticity large deformation, elastic recovery torque during the setting out of coiled bars is analyzed in accordance with the triple-roller equal curvature rotation blocking straightening system. To solve spring back effect bidirectional loading was introduced and this gave better results. The idler rolls rotate on needle bearings. Gear boxes are totally enclosed with hardened steel gears bathing in oil. The bars were straightened with good accuracy and the mechanism was analyzed using ANSYS.

Key Words: – Standstill locking mechanism, autorotation, springback effect, elastoplasticity, elastic recovery torque

1. INTRODUCTION

Round steel bars have got tremendous application in building, construction and maritime industries. Most of minor diameter ($d \leq 12\text{mm}$) commercial bars supplied

by Saibaba, Sree Rengaraaj Steels Pvt. Ltd are MS round bars that do not contain any alloying elements with carbon content not exceeding 0.25%, which can be used after straightening. Traditional manual straightening technique has low productivity and can't meet the need of the production. The parallel-roll straightening device raises the straightening speed greatly, but the bar rotates during the straightening processes. What is more, the straightening accuracy is low too. Therefore, this paper provides a roll-layout of equivalent curvature standstill-locking cum bidirectional straightening system that can straighten these bars with better accuracy. The mechanism is analyzed for deformation, stress distribution using Finite Element Software ANSYS

2. EXPERIMENT SETUP DETAILS

2.1. Bar Specification

A round bar of 10mm diameter was chosen for the process. The bar is made of mild steel. It is 1450mm long.

2.2. Stand still locking mechanism

In the straightening processes, bar is pre-straightened, and then its residual error reduces when it passes through the three-roll deformation. The deformation reaches equivalent curvature and it guarantees the bar doesn't rotate. At last, the bar is straightened via cyclic deformation in two orthogonal leveling flats, as shown in Fig.1. The wire rod of minor diameter bar adopts axial-feed technology, so the bar is twisted. The bend bar is used to setting-out before straightening and the torque of the bar is released, which causes the uncertainty of straightening plane because of autorotation of the bar. In the straightening processes, three roll deformation technology in this straightening system can keep the bar from rotating around its own axis, which

insures that the two orthogonal leveling planes don't change and two-dimensional straightening is fulfilled. While curvature residual of the same bar reaches equivalent curvature, which guarantees the bar's straightening accuracy. There are two self-locking systems in the process and the feed force has to overcome the locking press force. The self-locking system is equivalent to a simply supported beam with load at center.

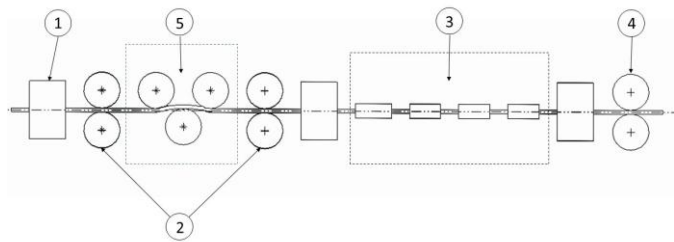


Fig -1: Diagrammatic sketch of straightening rolls system 1-Feed rollers;2-horizontal straightening rollers;3-vertical straightening rollers;4-guide rollers;5-standstill locking mechanism

3. CALCULATION OF PRESS FORCE APPLIED BY CENTRE ROLLER

The maximum deflection at centre is assumed to be $d=3\text{cm}=0.03\text{m}$ -----(1)

Where l =length between supports= 44cm , E =modulus of elasticity= $2 \times 10^{11} \text{ N/m}^2$, I =moment of inertia of bar= $\frac{\pi d^4}{64}$, d =diameter of bar= $10\text{mm}=0.01\text{m}$

Therefore, $I = \frac{\pi \times 0.01^4}{64} = 4.9087 \times 10^{-10} \text{ m}^4$

Substituting in (1) we get

Press Force $F_p = 1660\text{N}$

Taking coefficient of friction $\mu=0.7$

Feed force $=F_1 = \mu \times F_p = 1162\text{N}$

The diameter of feed roller, $D=75 \text{ mm}$. The mechanism is designed to complete the straightening process within 10-20sec.

Hence required feed $v=18 \text{ cm/s}$

But $V=R \times w \text{ m/s}$

Angular speed of feed roller $w = \frac{v}{D/2} \text{ rad/s} = \frac{0.18}{0.0375} = 4.84 \text{ rad/s}$

Since there are 2 self-locking mechanisms

Total feed force to be provided by a pair of feed roller $= 2 \times F = 2 \times 1162 = 2324\text{N}$

Torque of feed roller $T = F_t \times \frac{D}{2} = 2324 \times 0.03718 = 86.41 \text{ Nm}$

Total power $= 3 \times T \times w = 3 \times 86.41 \times 4.84 = 1254.67 \text{ W} = 1.68 \text{ HP}$

Hence 2 HP motor is to be used.

Spring force on each spring $= \frac{F_t}{\mu} \times \frac{1}{2} = \frac{2324}{2 \times 0.7} = 1660 \text{ N}$

Total vertical force $= 2 \times 1660 \text{ N}$

$= 3320$ -----(2)

Thus the spring of stiffness 52 N/mm is chosen.

Speed of feed roller $= N = w \times \frac{60}{2\pi} = 4.84 \times \frac{60}{2\pi} = 46.22 \text{ rpm}$

The maximum vertical force acting on the bar is 3.32 KN and maximum horizontal force acting is 2KN .

4. REDUCTION OF AUTO ROTATION BY SELF LOCKING MECHANISM

Elastic recovery torque causing autorotation

$M_t = \frac{2}{3} \pi r^3 K (1 - \frac{1}{4} (\frac{r_s}{r})^2)$ -----(3)

Where M_t = autorotation torque in Nm, r = radius of bar = $10\text{mm} = 0.01\text{m}$, K = Shear yield stress

$K = \frac{\sigma_s}{2}$ by Trescas theory of failure, σ_s = tensile yield stress= 400 Mpa , $K = 200 \text{ Mpa}$, r_s = radius of corresponding elastic range is given by $r_s = \frac{Kr}{G\gamma}$ -----(4)

Where G = modulus of rigidity = 80 Gpa , γ = maximum shear strain = $\frac{r}{R}$, R = radius of curvature of bend = 0.28m , Radius of curvature is given by $\frac{4l}{2\pi}$.

Thus $\gamma = \frac{0.01}{0.28} = 0.0357$

substituting values in eq (4)

we get $r_s = 0.00125 \text{ m}$

substituting all values in (3) we get

$M_t = 109.2 \text{ Nm}$

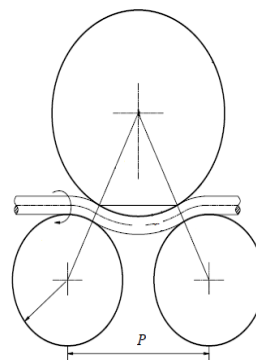


Fig -2: Deformation system

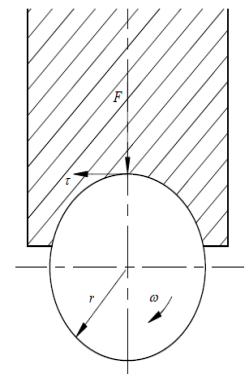


Fig -3: Force diagram of bar and rollers.

Reasonable design of roller diameter and spacing make the friction moment M_f which limit the bar's rotation satisfy the standstill-locking requirement. During the straightening processes, the torque of bar's rotation M_s must act on the entrance region of the large bending rolls when the friction torque that the pre-straightening rolls act on the bar is not enough to overcome the setting torque of the bars, shown in Fig. 2. The contact surface and force of the straightener roll and bar is shown in Fig. 2. Here the press that the straightening roll

acts on the bar is simplified as single force. Here the press force at centre roller is $F = 2776 \text{ N}$

The bending caused by the press force leads to a friction moment which limits the bar rotation.

$$T = \frac{1.66\pi^2 \mu \sigma r^4 (R+r)}{2PR} \text{ -----(5)}$$

Where, r =diameter of bar=0.01m, P = roller separation = 44 cm=0.44m, σ =tensile yield stress = 400 Mpa

R = radius of guide roller,

Substituting values in (4) and (5) we get $R=45\text{mm}$.

5. Three Dimensional Figure of the bar straightening mechanism

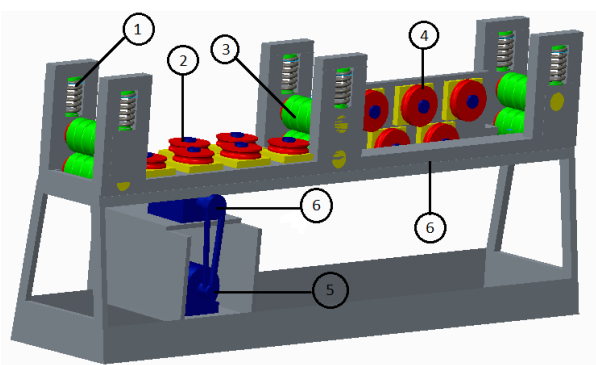


Fig -4: Three dimensional figure of the straightening mechanism

TABLE -1: Different components in the straightening mechanism.

PART NUMBER	PART NAME
1	SPRING
2	HORIZONTAL ROLLER
3	FEED ROLLER
4	VERTICAL ROLLER
5	MOTOR
6	GEAR BOX

The Fig -4. shows the three dimensional model of the straightening mechanism. It shows the positioning of components in the machine. It consists of six springs of same stiffness, guide rollers, feed rollers, stand-still locking mechanism, motor and gear box. The machine is 2.5m long and 1.5m high. The parts in the machine are mentioned in table1 with their part numbers. Motor and gear box plays the role of power transmission. The chain drive from gear box transmits power to the feed rollers without any slippage.

6. BAR STRAIGHTENING PROCESS

The bar specimen is passed through the feed rollers. It feeds the bar into the self-locking mechanism that prevents the bar from rotation. In the first stage there are rollers placed in horizontal direction that clears the bend in the horizontal direction. In the second section there are rollers fixed in vertical direction to reduce the bend in that direction. The feed rollers have enough power to guide the bars through the whole system. For one pass of the bar takes around 15 seconds that implies the speed of the machine. The results obtained after passing the bars through the straightening mechanism are obtained and graphs are plotted accordingly.

7. RESULTS OBTAINED AFTER THE STRAIGHTENING PROCESS

The straightness of the bar was measured using v-blocks and dial gauge as shown in fig. The straightened bar is divided into 8 equal parts. The points are marked at 0,17.5,35,52.5,70,87.5,105,122.5,140 in the bar and the straightness at those points were measured using the dial gauge. The values obtained for four specimens are shown in tables

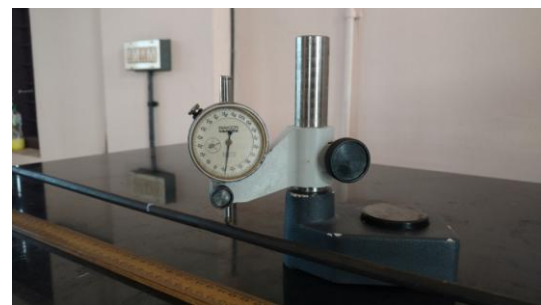


Fig -5. Measurement setup for straightness of round steel bar

TABLE -2: Straightness values obtained after measurement of steel bar specimen 1.

Position (cm)	Before passing (mm)	After first passing (mm)	After second passing (mm)	After third passing (mm)
0	0	0	0	0
17.5	56	4	2	1
35	123	12	4	2
52.5	158	18	7	4
70	143	25	11	7
87.5	146	16	6	3
105	106	9	3	1
122.5	43	3	1	0
140	0	0	0	0

The bending at various points on the bar specimen 1 before passing through the straightening mechanism were 0, 56, 123, 158, 143, 146, 106, 43, 0 mm. After the first pass the straightness improved to values 0, 4, 12, 18, 25, 16, 9, 3, 0 mm. The straightness is further improved in the second and third passes giving a desired precision of straightness ± 10 mm.

TABLE -3: Straightness values obtained after measurement of steel bar specimen 2.

Position (cm)	Before passing (mm)	After first passing (mm)	After second passing (mm)	After third passing (mm)
0	0	0	0	0
17.5	48	5	3	1
35	144	12	6	4
52.5	128	10	5	4
70	141	10	6	6
87.5	126	9	5	3
105	89	8	4	2
122.5	34	2	1	1
140	0	0	0	0

Initially the bending at various points on the bar specimen 2 were 0, 48, 144, 128, 141, 126, 89, 34, 0 mm. After the first pass the straightness improved to values 0, 5, 12, 10, 10, 9, 8, 2, 0 mm. The straightness is further improved in the second and third passes giving a desired precision of straightness ± 10 mm.

TABLE -4: Straightness values obtained after measurement of steel bar specimen 3.

Position (cm)	Before passing (mm)	After first passing (mm)	After second passing (mm)	After third passing (mm)
0	0	0	0	0
17.5	74	6	4	3
35	104	10	7	4
52.5	54	11	4	3
70	68	11	5	5
87.5	109	10	7	6
105	111	10	6	3
122.5	24	6	4	1
140	0	0	0	0

The bending at various points on the bar specimen 3 before passing through the straightening mechanism were 0, 74,

104, 54, 68, 109, 111, 24, 0 mm. After the first pass the straightness improved to values 0, 6, 10, 11, 11, 10, 10, 6, 0 mm. The straightness is further improved in the second and third passes giving a desired precision of straightness ± 10 mm. Using tables deflection curves were plotted against the positions in the bar specimens. It depicts the variation in straightness after each passing through the straightening mechanism.

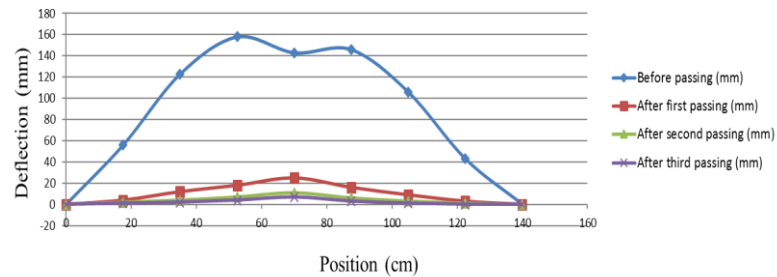


Fig -6: Straightness curve of bar specimen 1

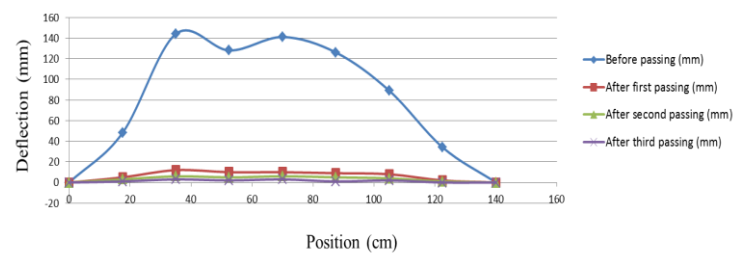


Fig -7: Straightness curve of bar specimen 2

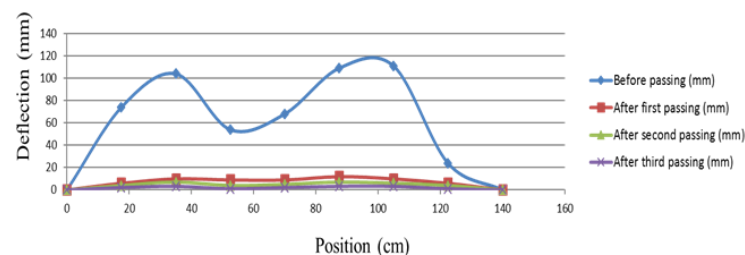


Fig -8: Straightness curve of bar specimen 7

The graph deflection vs position was plotted as shown in figures 6, 7, 8. From the above graphs it is concluded that before passing through the mechanism the bars had bending above 100mm and after passing through straightening mechanism the deflection was brought within 10mm range. With consecutive passes the straightness of the bar further improved that was clearly depicted by the graphs.

8. STRESS DISTRIBUTION, TOTAL DEFORMATION AND EQUIVALENT STRAIN ANALYSIS USING ANSYS

The total deformation, stress and equivalent strain developed in the bar was found out using finite element analysis software ANSYS. The bar dimension used for analysis was 1450 mm long and 10 mm in diameter. The density of the material was found to be 2020 kg/m³. The maximum force acts on the bar was found to be 3.32 KN (from eq. (2)). The total deformation, equivalent strain and equivalent (von-Mises) stress obtained are shown in Figs. 9, 10, 11.

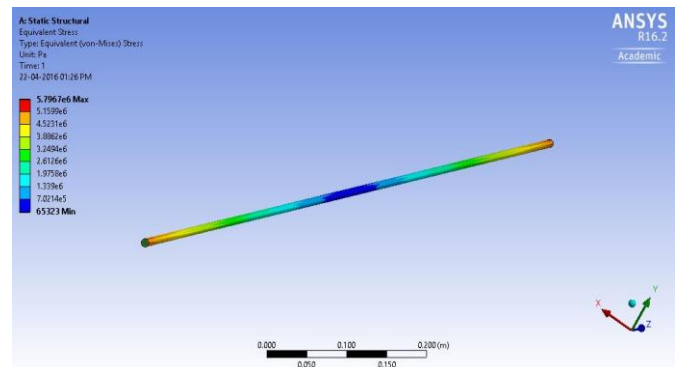


Fig -10: Equivalent stress developed in the bar

From the analysis the deformation of the bar was found to be very low during the straightening process, thus the bar damage was avoided. The stress and strain induced are within the allowable levels.

9. Conclusion

After conducting the straightening process for MS bars of 10mm diameter, a precision of $\pm 10mm$ was achieved. Autorotation of bar was prevented using the standstill locking mechanism. Using commercial finite element software ANSYS, it was found that during the straightening process the bar undergoes maximum deformation at the centre portion whose value was within the allowable range. The stress developed in the bar was well within the permissible limits for steel material. The results show that the design proposal of straightening system which is proposed in this paper is feasible and it provides favorable theoretical foundation for the development of commercial bar straightening machine.

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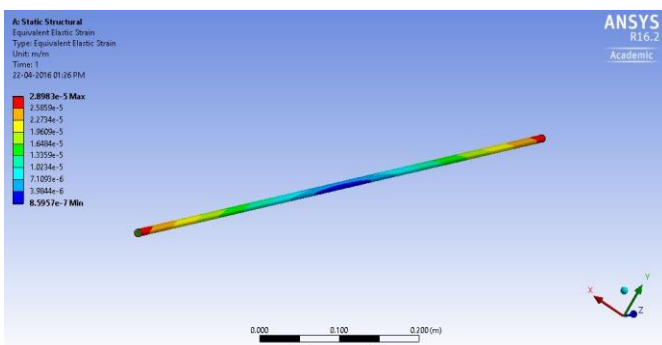


Fig -8: Total deformation of the bar.

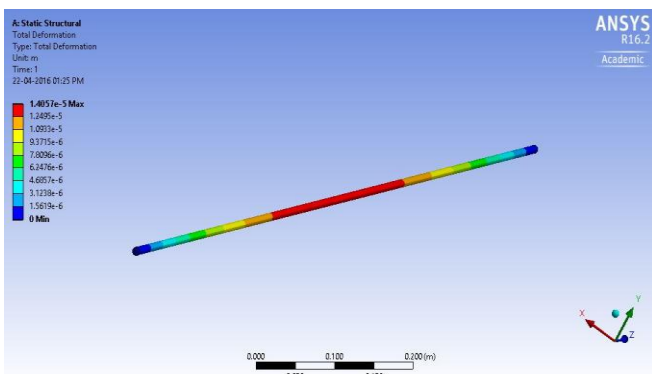


Fig -9: Equivalent elastic strain of the bar.

From analysis Using ANSYS it was found that during the straightening process the bar undergoes

1. Maximum deformation $1.4057 \times 10^{-5}m$
Minimum deformation 0 m
2. Maximum Equivalent Elastic Strain 2.89×10^{-5}
Minimum Equivalent Elastic Strain 8.59×10^{-7}
3. Maximum equivalent stress 5.79×10^6 Pa
Minimum equivalent stress 65323 Pa