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Research Article

Study of Air Starvation in Cellar at Wire Rod Mill

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Abstract

The mechanical properties of certain grades of wire at Wire Rod Mill (East) (WRM-E) were not matching within the desired limit even when the blowers inside the cellar ran on full load conditions. During preliminary study it was found that there was insufficient cooling of the wire rod. This led us to investigate air starvation within the cellar. A nonlinear mathematical correlation was developed based on Bernoulli's equation and the characteristic curve, i.e. Discharge vs the inlet area, for individual blower. It was observed that the air present inside the cellar was not sufficient to provide required outlet flow rate. It was concluded that the inlet area of cellar was not sufficient to fulfil necessary requirement of each blowers.

Keywords: *Wire rod coils, blowers, cellar, forced air cooling, stelmor system*

1. Introduction

The Wire Rod Mill (East) produces rod from billets through established process routes which culminate in the controlled cooling of the rod by forced air convection Stelmor system. Achieving the desired mechanical properties in the rod is dependent on sufficient and uniform air cooling applied to it as it passes down the Stelmor conveyor. Figure 1 shows the schematic of the WRM (E) manufacturing line. The total length of the Stelmor conveyor can be divided into five cooling zones. The first three cooling zones, consecutive in manner, are the fast air-cooling areas, fitted with double width double inlet type blower fan, for cooling the high carbon steel wire rods rapidly. The next two zones are the slow air-cooling areas used for alloy steel wire rods cooling are fitted with single inlet type blower. The wire rod coils are arranged to pass over the cooling zones in order to obtain the desired microstructure and corresponding material properties (D Raabea, 2012).

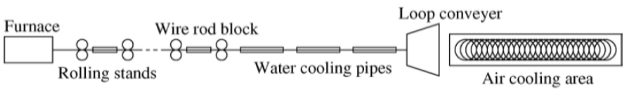

Figure 1 Wire Rod Mill manufacturing line at Tata Steel

There are total of ten blowers to ensure sufficient cooling and each zone is equipped with two blower fans to provide the forced air for cooling, and each fan is connected via a plenum chamber to the bottom of the conveyor deck as shown in Figure 2.

Air flows through a series of nozzles on the deck and up through the coils to complete the air-cooling process. All these blowers are kept in a blower chamber termed as a *cellar*. It is apprehended that the air inside the cellar may not be sufficient to provide required flow rate to cool the wire rod properly. Therefore, the objective of this work was to ascertain whether there exists an air starvation problem affecting the mechanical properties of wire rods when cooled.

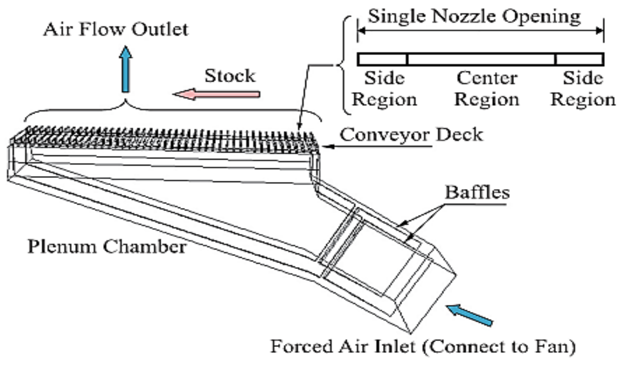

Figure 2: Schematic of the cooling system of Stelmor system

2. Theoretical Study of Blowers

To understand the starvation phenomena two cases have been compared in terms of work done by the blower (Miller et all, 2010). In first case, the inlet area of the cellar was taken as infinite, i.e. to the atmosphere and the second case where the inlet area was restricted as finite.

Case (1): *When the cellar inlet area was infinite*, taking $V_1 = 0$, then all the work done by the blower is used to provide required cooling flow to the conveyer and therefore the inlet and outlet boundary condition for an individual blower system can be expressed as shown in Figure 3.

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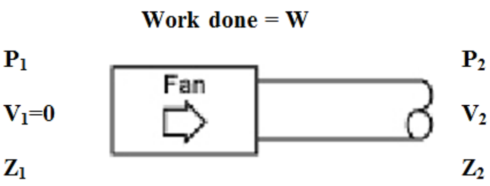

Figure 3: Cellar with infinite inlet

Case (2): *When the cellar inlet area is finite*, taking V1≠0, then work done by the blower is the sum of the work done to provide required cooling flow and work done to pull air inside the cellar through the cellar inlet. The inlet and outlet boundary conditions for an individual blower inside the cellar are shown in Figure 4. As a result flow rate gets reduced although work done by the blower is same in both cases, causing the starvation issue

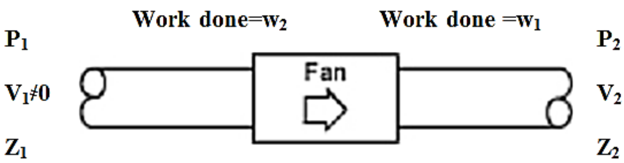

Figure 4: Cellar with finite inlet

Measurement of the intricate dimension

The Cellar or blowers chamber of Wire Rod Mill contain ten blowers and three gates for the air inlet. The respective position of the gates and the blowers is shown in Figure2 with a three dimensional schematic of the cellar configuration in WRM. The gates and the blowers are denoted by G1, G2, G3 and B1, B2 etc. respectively for better understanding of the problem. The dimensions of the gates were manually measured using the measuring tape to calculate the total inlet area available. The measured dimensions are; Area (G1) = 2.56 × 2.59 m^2, Area (G2) = 0.76 × 2.03 m^2, and Area (G3) = 0.81×1.98 m^2

Therefore the overall inlet area,

$$A_g = 9.8 \text{ m}^2 \qquad (1)$$

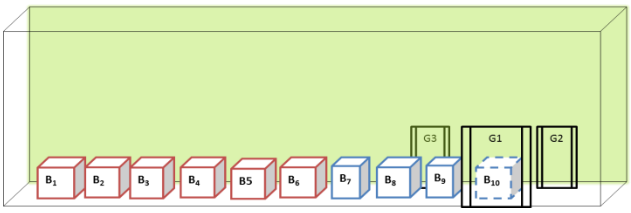

Figure 4: Schematic of the cellar with blowers and gates

The schematic of the blower duct configurations is shown in Figure 5. The length of duct, height of each blower from the ground and the cross section area of the duct were measured manually and cross checked with the drawing data to validate. It was verified that the area of duct (A_d) for all the ten blowers duct configurations were same and hence,

$$A_d = 0\ .75 \times 0.60 \text{ m}^2 = 0.45 \text{ m}^2 \qquad (2)$$

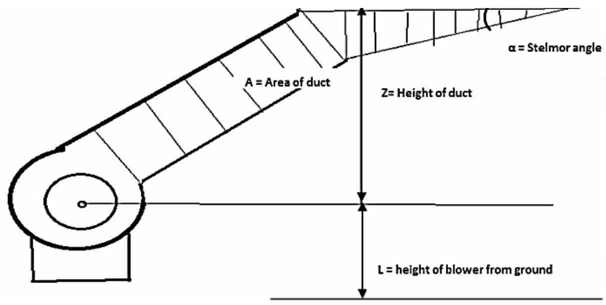

Figure 5 Blower duct configuration

The height of the duct, denoted as Z, for individual blowers was different calculated using the basic trigonometry with constant value of Stelmor angle (α). Stelmor angle (α) = $3^0 9'51''$ Therefore, the height of duct for each blower duct configuration was calculated as shown in **Error! Reference source not found.**.

Table 1 Calculated blower duct height

Blower no.	Z in m
1	3.538
2	3.596
3	4.377
4	4.434
5	4.493
6	4.551
7	5.003
8	5.061
9	5.119
10	5.177

Blowers Configuration

In

Figure **4**, blowers 1 to 6 are double width double inlet type with Input power of 150 KW (200hp) at 1440 rpm of impeller (Curch, 2010). The flow rate and static pressure of blowers (1 to 6) are:

Flow rate, Q_0=96000 m^3/hr = 26.6 m^3/sec

Static Pressure, ΔP = 310mm of H_20 =271.84 m of O_2 (3)

Similarly, Blowers 7 to 10 are single inlet type with input power of 90 KW (120hp) at 980 rpm of impeller.

Q_0=80700 m_3/hr = 22.416 m^3/sec

ΔP =162 mm of H20 = 142.06 m of O_2 (4)

3. Mathematical Model

With the help of Bernoulli's theorem and necessary boundary conditions (Smith), a non-liner equation model relating the flow rate and the inlet area available for an individual blower was formed under the relevant assumptions.

Calculation of experimental efficiency

To find the efficiency of individual blower; a single blower was considered as shown in Figure 6. The flow rate of the blowers was measured experimentally using ultra sonic wind meter. Applying Bernoulli's theorem (Miller *et al*, 2010), we get

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+Z_1+H_b=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+Z_2+H_s \quad (5)$$

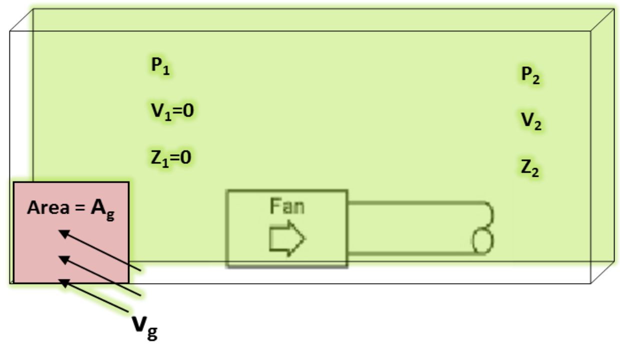

Figure 6 Schematic of cellar model for single blower

Where:
Z_2= Height of blower duct
H_b = Overall head provided by the blower
V_1 = 0 (since area near the inlet of fan is very large, so inlet velocity will be negligible)
H_s is the Starvation head accounted for the extra work which blower has to do to pull air inside the cellar. So it should be equal to the velocity head created at the inlet of cellar

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$H_s = (V_g^2)/2g$, (6)
V_g= velocity at the gate/inlet of cellar
P_2-P_1= static pressure difference between inlet and outlet.

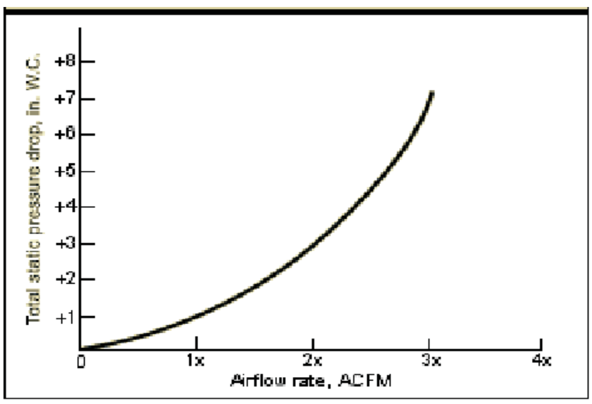

Figure 7: Blower characteristic curve

The characteristic curve of a blower is shown in Figure 7. From this, it can be inferred that the static pressure difference is directly proportional to the square of flow rate. Therefore, using the value given in (3) and (4), static pressure difference as a function of Q_2 can be found. Therefore,

$$P_2-P_1=(\frac{\Delta P}{Q_0^2})Q^2 \quad (7)$$

Using equation of continuity inside the cellar for air flow rate, we can say that volumetric flow rate of air entering inside the cellar through the gate/inlet should be equal to the outlet flow rate through the blower duct. Therefore:

$$V_g\times A_g=V_2\times A_d=Q \quad (8)$$

Using equation (5), (6) and (7), we get

$$H_b=\frac{(\frac{\Delta P}{Q_0^2})Q^2}{\rho g}+\frac{V_2^2}{2g}+Z_2+\frac{V_g^2}{2g} \quad Or \quad (9)$$

Using equation (8) and (9), we get

$$H_b=\frac{(\frac{\Delta P}{Q_0^2})Q^2}{\rho g}+\frac{(\frac{Q}{A_d})^2}{2g}+Z_2+\frac{(\frac{Q}{A_g})^2}{2g} \quad (10)$$

H_b (head provided by the blower) was calculated for measured outlet velocity (V_2) using ultrasonic wind meter and Ag, Ad, Δp, Qo from equation (1),(2),(3) and (4) simultaneously. Overall efficiency (η) of the blower can be calculated.

$$\eta=\frac{Work\ done}{Power\ input}=\frac{H_b\times V_2\times A_d\times\rho}{75\times bhp} \quad (11)$$

Correlation development

If we consider that for a given input the work done by the blower remains constant until a mechanical failure occurs inside the system, therefore it can be assumed that the efficiency of the blower shall remain constant. Based on this, the efficiency calculated from equation (11) is taken as a constant and therefore the flow rate (Q) and inlet area (Ag) are taken as variable. Therefore using equation (10) and (11), we get

$$\eta=\frac{\rho\left(Q^3\left(\frac{\Delta P}{{Q_o}^2\rho g}+\frac{1}{A_d^2 2g}\right)+Z_2Q+\frac{Q^3}{A_g^2 2g}\right)}{Bhp\times 75} \quad (12)$$

$$\frac{1}{A_g^2}=\left(\frac{\eta\times 75\times 2g\times(Bhp)}{\rho Q^3}\right)-\left(\frac{2\Delta P}{{Q_o}^2\rho}+\frac{1}{A_2^2}\right)-\left(\frac{Z_2\times 2g}{Q^2}\right) \quad (13)$$

Taking, $a=\frac{\eta\times 75\times 2g\times(Bhp)}{\rho}$, $b=\frac{2\Delta P}{{Q_o}^2\rho}+\frac{1}{A_2^2}$ and $c=\frac{Z_2\times 2g}{Q^2}$ as constants, we can write the final correlation as:

$$\frac{1}{A_g^2}=\frac{a}{Q^3}-b-\frac{c}{Q^2} \quad (14)$$

4. Results and Discussion

The constant used in equation (14) are computed taking the standard efficiency value of blowers available in

Table 2: Calculated value of coefficients for individual blower

S. No. of blower	η	Bhp	Δp (in m of air)	$Q_0(m^3/s)$	$A_d\,(m^2)$	Z_i (m)	a	b	c
1	0.65	200	271.84	26.6	0.45	3.538	169565.2	5.62007	69.3448
2	0.65	200	271.84	26.6	0.45	3.596	169565.2	5.62007	70.4816
3	0.65	200	271.84	26.6	0.45	4.377	169565.2	5.62007	85.7892
4	0.65	200	271.84	26.6	0.45	4.434	169565.2	5.62007	86.9064
5	0.65	200	271.84	26.6	0.45	4.493	169565.2	5.62007	88.0628
6	0.65	200	271.84	26.6	0.45	4.551	169565.2	5.62007	89.1996
7	0.68	120	142.06	22.42	0.45	5.003	106434.8	5.439813	98.0588
8	0.68	120	142.06	22.42	0.45	5.061	106434.8	5.439813	99.1956
9	0.68	120	142.06	22.42	0.45	5.119	106434.8	5.439813	100.3324
10	0.68	120	142.06	22.42	0.45	5.177	106434.8	5.439813	101.4692

literature (Stevens, 2008) and the other parameters of the blower are available from manufacturer manual, as shown in **Error! Reference source not found.**.

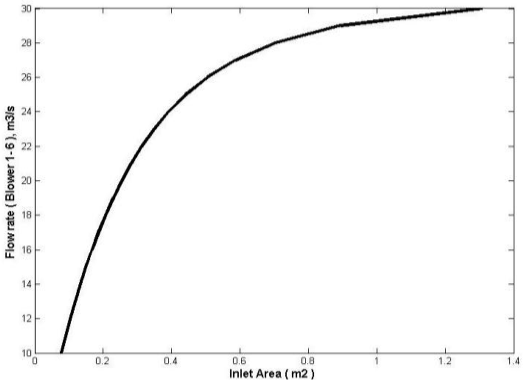

Figure 8 Q Vs A_g curve for blower 1, 2, 3, 4, 5, 6

Using the value of constants, the characteristic curve (Q vs A_g) were plotted in MATLAB™ using the equation (14) for individual blower and the total inlet area requirement corresponding to the required flow rate of individual blowers were computed. Blowers 1 to blower 6 were identical and the same current efficiency value was taken.

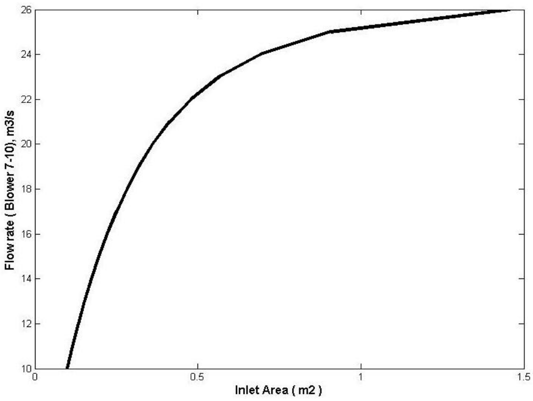

Figure 9: Q vs A_g curve for blower 7, 8, 9, 10

The plot between discharge or flow rate and inlet area is shown in Figure 8

Here, it can be seen that the inlet area required with double width double inlet blower for higher rating blowers, when runs at full capacity, is $1.31m^2$

Similarly, the characteristic curve for single inlet blower i.e. blower 7 to 9 were generated and are shown in Figure 9. The inlet area required when these blowers, run at full capacity, is 1.458 m^2

Thus, the overall area required when the entire blower run in full capacity was the sum of the individual area requirement of each blower is 13.8m2. The area available from the cellar of WRM (E) is 9.8 m2 from the equation (1).

The overall area available is less than the area required. Therefore it was concluded that there exist an air starvation inside the cellar. Also, it can be seen from Figure 5 that the gates for inlet i.e. G1, G2, G3 are located in a non-uniform manner.

Conclusion

The following conclusions can be drawn from the study:

1. A correlation between the outlet velocity of the blower and the inlet area of the cellar was developed.
2. It was found that the higher rating blowers i.e. blowers 1-6 are located far from the gates as compared to the lower rating blowers i.e. blowers 7-10 and therefore less inlet flow would be available to the former.
3. It was concluded that the current inlet of the cellar considering all the three active gates are not sufficient to provide necessary input air to the blowers. It is required to increase the inlet area by 4 m^2 or put an additional gate of the same dimension near blower 1. This can also be achieved if forced air is provided to the cellar through the gates by installing a fan outside.
4. Also, the inlet gates should be uniform throughout the cellar and not concentrated at one location- which is actually forming the dead zone near the blower 1 region.

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