Increase productivity of vertical roller mill using seven QC tools

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Abstract. Cement sector in India is enjoying success and capacity enhancement due to the rapidly growing demand in various sectors but at the same time a threat is approaching to cement industry that its input cost is increasing day by day like power cost, fuel cost, raw material cost. Also cement is a highly energy consuming industry. Hence in order to survive and sustain in the market its profitability need to be enhanced by increasing productivity and reducing power consumption. High productivity and low power costs can be achieved by increasing output, lowering breakdowns and optimizing the grinding process which eats almost 60% of power cost. In recent years vertical roller mill (VRM) has proved to be a popular choice for finished cement grinding due to low power consumption but it is also very sensitive to vibrations and can deteriorate productivity if process optimization is varied slightly. Objective of this research paper is process optimization of Vertical roller mill, improvement in productivity and reduction in vibration breakdowns using seven QC tools. The research explains complete process of identifying possible causes and final root causes, finding possible solutions and implementing them in order to increase the output of vertical roller mill. This study can benefit the organizations using VRM and are not able to utilize its full productivity due to some bottlenecks or constraints.

1. Introduction

India is the world's second largest producer of cement and produces more than 8 per cent of the total installed capacity globally. Due to the rapidly growing demand in various sectors such as defense, housing, commercial construction and industrial construction, it is expected to touch 550-600 million tones per annum (MTPA) by the end of year 2025.[11]

With recent growth and success journey there is also a threat approaching to cement industry that its input cost is increasing day by day. Power cost, fuel like coal cost, raw material cost have doubled up in recent years whereas cement price has not hiked in that fashion. Also cement is a highly energy consuming industry and 40% of cement production costs are energy costs out of which more than 60% of the total electricity is used in grinding circuits and hence bears most of the manufacturing cost. Hence in order to survive and sustain in the market they need to increase their profitability which can only be achieved by increasing productivity and reducing power consumption. These can be achieved by increasing output, lowering breakdowns and optimizing the energy consuming grinding process. For the past three decades the vertical roller mill has emerged to be the preferred choice for grinding raw materials[12]. It has advantages like low power consumption, process simplifications and compactness but it is also very sensitive to vibrations and can deteriorate productivity if process optimization is varied slightly.

The problems of high vibration and low productivity of VRM can be addressed using seven QC tools by identifying possible and responsible causes and working on to those causes by modifications & Kaizens[9]. Productivity can be enhanced by use of innovative products like grinding aids. The future of grinding is high productivity and lower specific energy consumption machines and machines having capabilities of adapting to complex processes and new advancements in technologies.[1]
2. Research Study
The study and research was conducted in a cement industry where Vertical roller mill was employed in cement grinding section. In this case problem was, Cement Mill was not performing as per its design parameters. It was a Vertical Roller Mill & is designed for rated capacity 215 TPH but its output was very low so specific power consumption was higher and contributing to loss in terms of production and in turn profitability.

2.1. Tools & Techniques Used

2.1.1. Data Collection

- To increase productivity of VRM - For primary pre-improvement phase data collection, SAP reports and monthly & daily MIS reports were used. Data of last 6 months was taken to analyse the exact nature. Data for production rate and specific power consumption were taken.
- To reduce vibration breakdowns of VRM - Last six months history of breakdowns related to vibration were collected with cause of vibration.

2.1.2 Defining & Solving the Problem
We have adopted following methodology & tools step by step:-

- Analysis of pre-improve phase data
- Brain storming sessions & defining the problem statement
- Captured all the probable causes.
- All probable causes put in the Ishikawa (Fish bone) diagram
- Critical issues were identified by Pareto Analysis chart.
- Brainstorming session to solve to critical issues and make action plan accordingly.
- Followed the PDCA cycle.

2.2. Problem Statement
Below shown Figure 2 is Production (TPH Tones per hour is measuring unit of production) and Specific Power consumption of Vertical Roller Cement Mill for pre-improvement phase. Data of last 6 months was taken to analyze the exact nature problem and behaviour of data.

It can be clearly seen that last 6 months average production Rate was 167.38 TPH & Specific Power consumption was 41.63 kWh/MT, which were below the rated design performance capacity of VRM. VRM was designed for 215 TPH. It means for every hour and hour we were loosing in terms of production and cement dispatch/sales and profit.

- What exactly is the problem? - Lower production rate than designed capacity
- Where? - Vertical Roller Mill
- When? - Since installation , data analyzed for 6 months
- Who is affected? - Production & Dispatch Targets
• How big? - Impact on sales and profit

![Image of VRM Production Rate and Specific Power](image1)

Figure 2. VRM Production Rate and Specific Power

It can be clearly seen in Figure 3 that last 6 months average breakdown frequency Rate was 60.16 tripping per month means per day more than 2 tripping. Excess breakdown results in frequent start/stop of VRM which consumes more power & also stability of Mill operation and productivity gets affected. Hence it was a big reason to worry & needed a solution.

![Image of VRM Monthly tripping due to vibration](image2)

Figure 3. VRM Monthly tripping due to vibration

2.3. Identify all possible causes

**Aim:** To identify and write all the possible causes for a mentioned problem.
**How:** Using concept generation tools, individuals or groups identify the causes of problem definition. Keep an open mind, do not confirm any suggestions at this stage and do not try to off track and analyze other issues.

**Main Tools Used:** Brainstorming, Cause & Effect Diagram

Tested all the factors related with Man, Machine, Method & Material area one by one with help of brainstorming. Which are segregated in Cause & Effect diagram shown in Figure 4 and listed below. The possible causes for constituting less TPH problem in 4M categories:

- I/P Feed Size - Clinker Size
- Fineness of the product
- Clinker hardness
- Skills of operator and attendants
- Grinding Pressure
- Separator Speed
- Inlet Hot gas damper and diverter, Recirculation Damper calibration
- Fan flow & Differential pressure PID tuning
- Mill vibration
- Breakdowns
- Grinding bed thickness
- Dam Ring
- Table & Roller Liners
- Water nozzle and water spray
- Weighing equipment Accuracy and calibration viz Solid Flow Feeder & Weigh feeder.
- Improper feed profile - Feed diverter calibration
- Capacity of critical material transfer equipment like Rotary air locks, Air Slides, Belts, Bucket elevators etc.

**Figure 4.** Cause & Effect Diagram for less VRM Production Rate
2.3.1 Material
- Clinker quality: Clinker's parameters play a vital role in productivity of mill, viz its hardness, size, composition. If clinker size is too small (Too fine like powder) it will not construct proper grinding bed and cause vibration. If clinker is too hard it will take more time to grind.[8,12,14]. Clinker found OK.
- Fly ash: Fly ash availability was not an issue with us. But fly ash Blaine was around 280-290 m²/Kg, which we require up to 320 m²/Kg. But Blaine of Fly ash was not in our control and Flyash cannot be ground solely to achieve required blain size. So it was a cause with no solution.
- Gypsum: Size of gypsum boulders were very high than required. High size boulders creates sudden up/down or Roller and Grinding pressure fluctuates. Also Sticky gypsum if not correctly handled may create problem in hoppers extraction and jamming in transfer points which ultimately results in feed rate variation.[8,12,14]
- Waste TAD Material: It causes lot of vibration, so its use was not advised. But its consumption was necessary.

Variations in feed rate increase vibrations of the mill, destabilizing operation and in the extreme resulting in mill stoppages. Observed feed variation in Fly ash.

The mill feed material needs to be free of metal pieces. Higher the metal pieces frequent operation of diverting gate and results in feed variation. [8,12,14]

Abnormal feed size and distribution may increase the level of vibration and destabilize the mill. Large feed size in any case will reduce the mill production rate. Excess fines in the feed material or reject from the separator can adversely affect the stability of grinding bed and can cause vibrations. [8,12,14]

2.3.2 Man
Skill and knowledge was not an issue, all operator were well trained a professionally qualified. Also Mill was in OEM operation for a long time to stabilize.

2.3.3 Method/Process
Operation optimization or process optimization is a critical step responsible for efficient operation of Mill.

It constitutes of optimization of operation parameters like Flow, Differential Pressure, Classifier Speed, Mill Inlet & Outlet Temp, Hydraulic Pressure, equipments, control logic, PID tuning, breakdowns etc. Some parameters like excess vibration, high numbers of breakdowns were observed which in turn needs further optimization.

- Mill DP - If differential pressure is too high or too low means mill is choked or empty. If DP transmitter is faulty then it shall indicate false reading and operator will not be abler to get correct condition of Mill inside filling.[14]
- Fan Flow - Fan flow & speed is very necessary to optimize for effective material transport.[14]
- Inlet & Outlet temp optimization is necessary to control material drying & outlet final material temperature.[14]
- Hydraulic pressure should be matched to the material load in the mill. Insufficient hydraulic pressure for the mill load will result in high circulating load and high pressure loss with potential over filling the mill. Excessive hydraulic pressure for the load will result in a thinning of the bed and increased vibration /wear.[14]
- Water spray is used to help stabilize the grinding bed and maintain a low level of vibration and generally this is applied directly to the material on the table, immediately before it passes under the grinding rollers. Excessive addition of water to the table can result in increased wear and even thermal shock of the grinding elements. Water spray optimization required.[14]
Grinding bed is the material layer formed between the roller and the rotating table. It transmits the entire roller force and mill power. It is the key factor for successful operation of a VRM. Requires optimization.[14]

Mill vibration to be controlled to avoid unnecessary breakdowns and wear tear in mill components. Found excessive tripping need to be optimized.[14]

Interlocks optimization required.

2.3.4 Machine

Efficiency of machine and desired production are related to each other. If machine operates well then it will give required production effortlessly.

- While checking found material transfer equipment (Bucket elevators, Belts, Air slides) capacity adequate and fit of required operation - 300 TPH capacity.
- Calibration of critical measuring devices like Weigh feeders & Solid flow meter found OK.
- Metal detectors calibration found OK
- Wear of the grinding elements increases the material retention upon the table and tends to increase mill power drawn. Uneven wear of grinding elements leads to reduced mill efficiency due to non-uniform transmission of grinding energy to raw material. Mill feed table & grinding rollers profiling found Ok as desired.
- The dam ring is used to control the bed depth in order to stabilize the grinding efficiency and vibration. Too high Dam Ring –excessive bed depth, inefficient grinding and high power consumption. Too low Dam Ring –low bed depth, high vibration and high recirculation. Dam ring height optimization required to control rejects.
- Water nozzle modification required as excess chocking is noticed.
- Inaccuracy of Roller position and speed sensor: - If roller position sensor is not calibrated properly, it will show wrong position/height of roller and Operator in central control room will get confused and will assume that roller is forming correct bed and grinding properly whereas situation is opposite. Found OK.
- Fan Flow - Fan speed controller, or speed sensor or Flow sensor transmitter is faulty or unreliable than optimization and tuning will not be as desired. Found OK.
- Blockage of pressure tapping, particularly mill inlet and air flow measurement points. OK.
- Out of calibration bed depth monitors & other instruments like PT, TT etc. Found OK.
- OEM design issues - Hydraulic system, cone stump design, and classifier design.

2.4. Finding Potential Causes

During the analysis of the causes related with the area of Method, Material & Machine tested probable causes one by one and found 4 causes have some significance on the effect in cement grinding : -

2.4.1. Actual/Potential Causes

- Poor process/operation optimization, High breakdowns
- OEM related design issues - Hydraulic System Design
- Fly ash Blaine not suitable

2.4.2. Solutions

- Operation optimization by PID tuning, Grinding bed optimization etc.
- Grinding Aid Implementation to increase output
- Reduction in breakdowns (Related to vibration)
- OEM related design issues - Hydraulic System Design
2.5. Implementation of Potential Solutions

2.5.1 Operation optimization:-

2.5.1.1 All PID Control loops tuned:-
Though at the time of commissioning of mill all PIDs were tuned but after years of operation many parameters and interlocks were changed but still PIDs were at the same. Also some control loops were not in circuit. So to optimizer the mill performance all PIDs were taken into circuit and tuned at the best level manually. There were 4 control loops for Differential Pressure, Mill outlet temperature, Mill ventilation fan flow and Mill inlet pressure.

a) Differential Pressure
The mill differential pressure is the difference between pressure at mill inlet and mill outlet representing currently loading condition of the VRM. Changes in the differential pressure when the grinding pressure and the hot air circulation are constant, directly reflects the amount of material in the mill. In other words, when the differential pressure decreases, the amount of input material is less than the discharge material, causing the material bed to be thinner. In contrast, as the differential pressure increases, the material bed becomes thicker. VRM vibrates when the material bed is too thin or too thick and trips or stops when the vibration limit is exceeded. For these reasons, the total feed amount must be adjusted so that the differential pressure is within the correct range.[4,7]

The differential pressure of the mill depends on the following parameters:

- Input material feed rate
- Mill fan flow rate
- Grinding pressure
- Classifier speed

Usually only the mill input material feed rate has a decisive influence on the differential pressure while gas flow rate, grinding pressure and classifier speed are maintained at the similar condition according to the pre-adjustments during previous operation unless the characteristics of the raw material such as the grind ability of the material has been changed. [4,7]

So to optimize the DP PID, we made a PID interlock in which PID algorithm can estimate the desired volume of material feed, according to which the feeding control module can control the velocity of the conveyor belt through the frequency converter. If DP is low, belt speed will be increased and if DP is high then belt speed will decrease automatically.[4]

Figure 5 shows the PID control structure of the differential pressure, where k1, k2, k3, k4 are proportions of Clinker, Gypsum, High grade lime stone & Fly Ash in the raw materials.

![Figure 5. VRM Differential Pressure V/s Mill Feed PID Loop](image)

b) Mill Outlet Temperature / Material Temperature
The gas temperature at mill outlet is a measurement of the drying process accomplished in the mill. The mill outlet temperature can be controlled by controlling the recirculation air damper or inlet hot gas fan speed and also can be cooled down by opening the fresh air damper. To achieve an effective
drying, outlet temperature is generally regulated between 80°C and 100 °C to regulate the quantity of water spray in the mill. When the outlet gas temperature exceeds Tupper, the quantity of water spray should be increased, even as the water spray system stops when the temperature is under Tlower. Fig. 6 illustrates the PID control of VRM outlet temperature.[4]

![Figure 6. VRM Outlet Temperature V/s Water Spray PID Loop](image)

**Figure 6. VRM Outlet Temperature V/s Water Spray PID Loop**

c) Mill Fan Flow / Transport Air Flow
The hot air in the mill plays a role in drying and transporting the material. Adequate ventilation not only improves grinder efficiency but also contributes to the stability of the mill. This ventilation can be measured behind the bag filter and controlled by controlling Mill Fan speed by controlling fan motor speed through variable frequency drive. The control structure is tuned to achieve good performance. The preset module calculates the amount of ventilation required to dry feed material and the amount of ventilation required to transport the material according to the heat balance equation and compares the two pits. When the amount of ventilation required for dry materials is greater than that used for transportation, it is set to the required ventilation. In contrast, the amount of ventilation used for transport is selected as the desired set point. During the manufacturing process, we control the fan speed so that there is ventilation in the mill to meet the drying and transportation requirements.[4,7]

d) Mill inlet negative pressure (Draft)
The hot air used in grinding process is taken from the kiln, and the operation condition of grinding system and the kiln influence each other. The mill inlet pressure should be maintained at constant value. The static pressure measured at the mill inlet gas duct is influenced by the gas flow entering into the mill by mean of:

- Recirculation air damper
- Hot gas generator or Booster Fan
- Fresh air inlet damper

Too high negative pressure before the mill increases the energy consumption of the mill system fan. However too low negative inlet pressure influences the steady gas flow within the system and leads the grinding system into disturbances.[7,8,12]

2.5.1.2. Grinding bed height optimization through Dam Ring:
The grinding bed thickness, defined as the minimum gap between the grinding rollers and the grinding table during the operation, is adjustable by the height of the dam ring the grinding pressure and mill circulation load during commissioning[7,12]. Dam ring is shown in figure 7.

The thicker grinding bed gives narrower particle distribution but results with higher power consumption and softer operation. Nevertheless the thinner grinding bed gives wider particle distribution but with lower power consumption and rougher operation. The optimum grinding bed thickness shall be decided during commissioning[14].

Dam ring height optimized in various phases and best result found at 340 mm.
2.5.1.3. Reduction in Mill Vibration:-
Separate brainstorming sessions were done as vibration tripping was very high and Mill was unstable. Optimization of the mill became very difficult due to vibration and instability. So to stop production loss on daily basis and to ensure smooth and optimize Cement Mill operation, we have to solve this at first priority.

a) Analysis Tools: To solve this problem following QC tools were used:-
   - Pareto Chart.
   - Cause and Effect Diagram

b) Pareto Chart: To analyze the major reasons for vibrations, last 6 months data for Mill breakdowns due to vibrations was collected from breakdowns history and segregated in cause for vibration. Based on the same pareto chart was prepared. From the chart it was found that 82% of the tripping were due to 3 main problems:-
   - Sudden vibration peaks
   - Fly ash feed fluctuations
   - Water problem

Our further action was to address the possible causes for these 3 main tripping. For this we decided to employ pareto chart for mill tripping due to vibrations. In last 6 months total 361 tripping occurred due to vibration. Pareto diagram is shown in figure 8 & pareto table is as following:

| S. No. | Cause of Tripping / Breakdown                     | Frequency | % Contribution | Cumulative % |
|--------|---------------------------------------------------|-----------|----------------|--------------|
| 1      | Vibration due to Sudden peak in Mill vibration    | 184       | 50.96          | 50.96        |
| 2      | Vibration due to Fly Ash fluctuation              | 65        | 18.00          | 68.96        |
| 3      | Vibration due to Water spray problem / Water Tank empty | 47        | 13.01          | 81.97        |
| 4      | Vibration due to Dusty / Fine Clinker             | 29        | 8.03           | 90.00        |
| 5      | Vibration due to foreign metal in Mill            | 18        | 5.00           | 95.00        |
| 6      | Vibration due to HSLM / Grinding Pressure fluctuation | 18        | 5.00           | 100.00       |
| **Total** | **361**                                          |           | **100**        |              |
c) Cause and Effect Diagram :-
All the possible reason for the vibration was discussed by team members and lots of point came out which were further discussed and categorized. Cause & Effect diagram is shown below in Figure 9 :-

Following were found to be possible causes for constituting vibration problem in 4M categories:-

i. Material:-
- Dusty and Fine clinker cause improper bed formation. Creates vibration
- Lumps in Gypsum and TAD material causes sudden up/down of M Roller causing fluctuations and vibration
- Fluctuations in Fly ash means High or Low fly ash flow at sudden causes inconsistent feed flow and causes vibrations.
Fly ash fluctuations can be a result of Splitter positioning problem
Solid Flow meter calibration error, it misleads about exact feed in mill and creates material shortage or excess in the mill creating vibration.
Weigh feeder calibration error it misleads about exact feed in mill and creates material shortage or excess in the mill creating vibration.

ii. Machine: -

- Water nozzle wear out causes improper water flow and distribution.
- Chocking of water nozzle during stoppage of mill creates uneven water spray
- Water tank level control problem. Level sensor or solenoid valve problem. Due to it water tank empties out during operation and due to water shortage Mill trips due to vibration.
- Damring height plays a big role in mill stability. Low dam ring height causes less bed formation and causes vibrations, it also increases mill reject.
- Metal detector accuracy plays a big role, if MD doesn't sense metal then it will go in mill and creates vibration if it comes between table and roller.
- Accuracy of Vibration sensor and it's installation (If it is exposed to foreign material)
- Inaccuracy of Roller position and speed sensor: - If roller position sensor is not calibrated properly, it will show wrong position/height of roller and Operator in central control room will get confused and will assume that roller is forming correct bed and grinding properly whereas situation is opposite.
- Mill DP - If differential pressure is too high or too low means mill is choked or empty. If DP transmitter is faulty then it shall indicate false reading and operator will not be abler to get correct condition of Mill inside filling.

iii. Method: -

- Disturbance in feed - Mill reject hopper diverter timing in case of metal detect. In case of metal detection, diverter divert the input feed to reject hopper so that metal cannot go inside the mill and create wear/tear or vibration. As metal is detected the diverter operated towards Reject hopper side for a particular time and then comes back in main feed to mill. If diverting and transition time is not optimized then it may create loss of feed into mill and in turn creates vibration.
- Difference in Roller height due to Hydraulic system problem.

And from above analysis main reason came out were as following:

- Fluctuation in Flyash Feeding due to initial inrush (Solid Flow Meter Dosing valve)
- Fluctuation of Flyash due to Empty out of Bin.
- Jamming of Flyash in Bin Extraction due to foreign material.
- Lumps in TAD Material.
- Chips of hard facing of Dam ring found in mill during inspection. It is a hard metal and causes vibration when comes in between Roller and table
- Water Problem due to Tank empty (Level sensor problem), Wear of water nozzle, Chocking of Nozzle.
- Disturbance in feed due to Metal detector and Reject diverter operation.
- Roller no. 3 profiling was not proper, it creates vibration.
- Big size gypsum boulders & big size of Performance improver High grade lime stone.
d) Action Plan:

| SN | Action to be taken                                                                                                      | Target Date | Status          |
|----|-------------------------------------------------------------------------------------------------------------------------|-------------|-----------------|
| 1  | TAD material to be avoided in case of PPC.                                                                             | After consumption of TAD dust. | Done            |
| 2  | Water spray to be optimized by using one pump instead of two. Providing High capacity pump & VFD to control the speed. Also providing reliable water flow meter | 28 Feb - Requires new material | Done            |
| 3  | Nozzle chocking is eliminated by providing bypass compressed air & interlock , when mill stops Compressed air will clear the water nozzle in every 30 minutes | 31 Jan      | Done            |
| 4  | For tank empty out problem, new radar level sensor to be installed and one interlock to be provided for auto start of pump to avoid emptying of water tank. | 28 Feb - Requires new material | Done            |
| 5  | Gypsum size should be restricted to 50 mm.                                                                              | Not Uniform |                  |
| 6  | Fly Ash blaine need to be increased                                                                                    | Not Uniform |                  |
| 7  | Performance Improver (L/S) to be used of size < 50 mm for better bed formation.                                        | Not Uniform |                  |
| 8  | Diverter plate modified to decrease the inlet temp. Difference.                                                        | Done still under observation | Done            |
| 9  | Flyash Bin V/S Bin Weight PID to be provided after dosing valve problem rectification to overcome flyash empty out issue. Also Wire Mesh to be provided to prevent Lumps or foreign material in Bin. | 31 Jan      | Done            |
| 10 | To avoid flushing in fly ash ,interlock with aeration blower is modified                                                | 31 Jan      | Done            |
| 11 | To avoid Flyash fluctuation at Mill startup after a long time, Dosing valve interlock is modified. It will open 100% in start and After 1 minute if will come to 50% open | 31 Jan      | Done            |
| 12 | Ash splitter to be checked in every shift                                                                                | 15 Jan      | Done            |
| 13 | Calibration of Flyash Bin with proper test weights.                                                                     | 20 Jan      | Done            |
| 14 | Calibration of Solid flow meter & daily check weighing                                                                  | 25 Jan      | Done            |
| 15 | Calibration & Daily checking of Metal Detector                                                                            | 15 Jan      | Done            |
| 16 | Optimization of reject diverter timing during metal detection. It is to be reduced to 4 second.                         | 15 Jan      | Done            |

2.5.2. Grinding Aid Addition
Grinding aid reduces the polarity of the cut surface and the attraction forces between particles. This means that agglomerates of fine particles and the packing of fine particles around a larger particle are dissipated, resulting in an improved classifier efficiency. The internal circulation of fine particles becomes lower and the clinker on the grinding track becomes coarser. The inter-particle friction and thereby the effectiveness of the grinding process is increased. In this way, grinding aid stabilises the grinding bed on the rotating table, facilitate compaction and de-aeration, improves productivity and lowers vibration in the system.[6]

Benefits of adding Grinding Aid: -
Table 3. Benefits of adding Grinding Aid in VRM

| Effect on separation | De-agglomeration               |
|----------------------|--------------------------------|
|                      | Higher efficiency, less recirculation |
| Effects on grinding bed | Few fines, coarser clinker     |
| Effect on grinding | Improved grinding               |
|                      | Ease of de-aeration             |
|                      | Less vibration, less wear and tear |
|                      | Low water requirement            |
| Effect on productivity | Reduced mill differential pressure |
|                      | Productivity improved           |
|                      | Lower specific energy demand    |
| Effects on final product cement | Broader particle size distribution |
|                      | Increased powder flow ability    |
|                      | Reduced pre-hydration of cement |
|                      | Fast initial setting             |
| Effects on concrete | Improved mortar workability      |
|                      | Strength in concrete             |

To test the effects of grinding aid, we also tested it by adding some amount of Grinding Aid on experiment basis. All vital parameters were kept same in testing With/Without adding grinding aid. Dosing of grinding aid was 75-80 Liters per hour. The test results were found to be positive, we witnessed increase of 7.66 Tonnes per hour and reduction of 2.34 kWh/T specific power, which is a very appreciating figure.

Table 4. Results of Test on VRM

| Date       | Power consumption kWh/Ton | Production Rate TPH |
|------------|---------------------------|---------------------|
| With grinding Aid |
| 11-02-2019 | 34.55                     | 195                 |
| 12-02-2019 | 34.22                     | 198                 |
| 13-02-2019 | 32.04                     | 201                 |
| Average    | 33.60                     | 198                 |
| Without grinding Aid |
| 15-02-2019 | 36.36                     | 185                 |
| 16-02-2019 | 36.10                     | 188                 |
| 17-02-2019 | 35.38                     | 198                 |
| Average    | 35.94                     | 190.33              |
| Difference | -2.34                     | 7.66                |
2.5.3. OEM Related design issues
After brainstorming sessions and discussion with OEM some modifications were suggested:

a. Support Roller Interlock - Support roller are employed for grinding bed formation. But also its size creates a demerit that it hinders recirculation inside mill and obstructs the free flow of material towards classifier. Hence recirculation time in mill increases resulting in low production rate. This was the case for our project. Hence with the consent of OEM we tried mill operation without employing the S-Rollers operation and we found stable mill performance with optimum DP, less vibrations & improved circulations inside mill.

b. HSLM Modification: - The VRM has 3 Master rollers and earlier there were separate Hydraulic system for each rollers. So for roller Up/Down and Increasing/Decreasing Grinding pressure, no symmetry was achieved constituting unstable operation and increased breakdowns. Later OEM suggested a modification to have a single Hydraulic circuit system for all 3 rollers so now on excellent hydraulic control achieved. Which resulting in no pressure difference hence less breakdowns. This project was done by OEM.

c. Cone stump diameter changed from 1988 mm to 2240 mm in Sep 2018. Role of cone stump is to distribute material via centrifugal force to grinding roller area. Earlier smaller cone stump was not able to distribute fully and some material was kept ungrounded on feed table. Now with bigger cone stump this situation is addressed fully with effective distribution and grinding.

2.5.4. Fly-Ash Blaine: - Increase fly Ash Blaine from 290 to 320
Fly-ash is a major supply for any cement plant now a days because every producer wants to produce more PPC than OPC due to profitability and increased output.

Our required Blaine for PPC is 320 M2/Kg of material. For PPC our proportion is 65% Clinker + 35% Fly ash. Hence need less time to produce PPC as it required Grinding of only 65% of material and rest 35% Fly ash is blended in Mill. So there is less power consumption and more output in case of PPC rather than OPC cement.

Now if we get a Fly ash of Blaine size 320 then it will be a boon for us as we just need to put it in mill and very less retention time it will become final product output. But the Fly ash blain at our point was 290 M2/Kg only.

Major source for Fly-Ash supply is Power plants nearby and blaine of Fly-Ash is not in our control as we cannot force our suppliers. Cement industries get fly ash at a very minimal cost.

Other source for Fly ash was our own small size captive power plant. But our blain size was also 285-290. We can get blain size of 320 only if we fire F-Grade coal in our boiler, but in actual we were firing PET Coke. As cost of PET coke is less than F-Grade coke.

- By increasing Fly Ash from own TPP - This will be possible after usage of F Grade coal in TPP.
- By increasing Fly Ash Blaine from Supplier - As Fly Ash Blaine supplied is constant and not in our control.

3. Results
After implementation of all the planned jobs and action plans, data is collected for production rate and breakdowns for 5 months (2 months of implementation stages & 3 months after) and presented them in graphical form. From analysis of data following results were found to be achieved:

3.1. Tangible
- Increased average mill productivity from 167.38 TPH to 194.34 TPH. Means 26 Tones per hour increased. If we consider 22 hours a day running then it will be 22 X 26 = 572 Tonnes per day.
- Saving due to increase in production = 572 * 750 = 4, 29,000 Rupees per day.
- Average monthly tripping of vibration is reduced in significant numbers from 60.16 to 29.3 tripping per month means approximately 50% improvement.

3.2. Intangible

- Stable Mill Operation.
- Reduced breakdowns, Increased MTBF & OEE of Mill.
- Improved cement dispatch & targets are met.
- Reduced Wear & Tear of mill internal components
- Reduced vibration level of mill, so overall equipment life enhanced

![Figure 10. Results - Tripping of mill due to vibrations (Before & After)](image1)

![Figure 11. Results - VRM production rate - After](image2)
4. Conclusion
In recent years Vertical roller mill has been a popular choice for material grinding due to advantages like low power consumption, process simplifications and compactness but it is also very sensitive to vibrations and process parameters variation.

Operation stability and better productivity can be achieved if all process parameters and interlocks are optimized and kept well under control. Reasons for process disturbance and breakdowns should be identified and addressed. To identify possible and responsible causes, seven QC tools can be utilized.

QC tools like brainstorming, Pareto Analysis, Cause and Effect Diagram and Problem solving process can be used to identify and remove the bottleneck in the process. Further working on to those causes by modifications, kaizens and process improvements, can lead to better productivity, lesser breakdowns and lower power consumption.

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