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Research paper

Reliability Measurement of Torque Transmission System for Spice Manufacturing Plant

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Abstract

Growths of present day industries are forced towards the use of automation and more complex system. Currently, the manufacturing line that makes up with thousands of complicated components and make any failure of one or more components may affect the entire production system. In order to deal with this issue, preventive maintenance scheduling that to keep the machinery downtime as low as possible while reducing maintenance cost becomes a challenge to the process industry. In this regards, many factors such as maintenance practice, availability of maintenance repair & overhaul (MRO) spare parts and skilled of labor plays a major role to lead the industry stable and running at optimum condition. This paper presents the comparison breakdown frequency, and production output between belt driven, and gearbox driven vertical roller mill. In this study, the reliability for torque transmission system that used in for spice-based food industry has been evaluated. The breakdown cost and the reliability data were evaluated. In addition, the mean-time between failure (MTBF) and mean time to repair (MTTR) for critical components that significantly suggested for the preventive maintenance strategy were also calculated. With lesser failure frequency and more reliable availability of 99.47% as compared to 96.81% of gear box driven mill, the belt drive is concluded as the most effective drive system for pendulum roller mills.

Keywords: *Drive System; Manufacturing; Maintenance Management; Maintenance Strategy; Preventive Maintenance*

1. Introduction

Effective engineering management or more specifically, maintenance management is essential in any manufacturing environment. One of the key issues in the manufacturing industry would be keeping the machinery downtime as low as possible and concurrently keeping maintenance costs low too. In that regards, many factors such as maintenance practice, stocking of MRO (Maintenance Repair and Overhaul) spare parts, skilled labor cost and many other factors plays an important role to lead stable machineries running conditions, without down times. Torque transmission system for any machinery may vary significantly depending on the design, construction, and application of a machine. The optimum selection of a drive system is largely based on case to case interest of any organization and their maintenance strategy. This paper presents a situation with respect to the maintenance strategy of an organization of spice manufacturing plant.

Quality plays an important role in today's highly competitive industrial environment. Quality leads to an improvement in the productivity. Best practice of high quality maintenance scheduling helps to the industry and machinery to be well maintained and maximize the output, reliability and profitability. Failure analysis is the process of collecting and analyzing data to identify the root causes of a failure and to determine corrective actions for them. Failure data are the backbone of reliability studies as they provide very useful information to reliability engineers, design engineers and managers [1, 3]. It is a vital tool used in the development of maintenance strategy for any equipment, development of new products and in the improvement of existing products. Various sources of collecting failure data are available, but inspection records, log books generated by maintenance, quality control or manufacturing groups are widely used.

The organization has specific machineries comprising fine grinding equipment such as pulverizes, vertical roller mills, hammer mills and granulators. The major machines in the plant refer to rotating machinery that fine grind the raw material which undergoes high shock loads or high rotational speeds and inevitably face high fatigue or failure rate. The most common industries known to utilize this grinding machine are the mineral ore, cement, coal and spices industries [1]. Lubricant absorbs heat from higher temperature regions and transfers them to a comparatively lower temperature region where it is dissipated, by which means the temperature of the system is kept under control [2].

This study focuses on vertical roller mills used to grind the 'chili' flakes into fine powder, and its productivity for different drive systems, namely belt drive and gearbox drive. It had been identified that the source of contamination in cotton lint in the process was the gearbox of the double roller gin. This marks the weakness in gearbox driven systems [3]. In comparison to the traditional V-belts, V-ribbed belts have numerous advantages including accommodation to smaller pulleys sizes and belt lengths, backside operation, and relatively longer service life [4]. The study will discuss the current technological advancement in the vertical roller mill construction, operation and maintenance practices, whereby providing a clearer view on selection of optimum torque transmission system for the vertical roller mills. Current set-up of pendulum roller mills in the organization is using belt drives or gearbox drives for several different lines. Hence, the mills require different maintenance practice and spare part inventories to be kept in stock. An opportunity to improve the reliability, and standardize inventories and maintenance practice of the pendulum mills is to be evaluated, with regards to the productivity of the mill will be evaluated.

2. Methodology

The framework as shown in Figure 1 represents the sequence of methods that shall be followed to accomplish the outcome of this study.

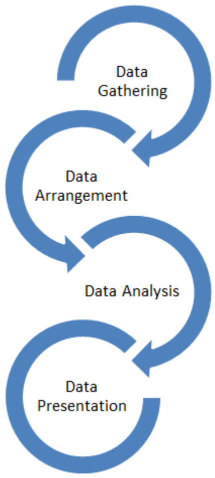

Fig. 1: Operational framework

A vertical roller mill has multiple numbers of roller arms suspended on to a sleeve fixed to a centre shaft, which is able to rotate about a fixed vertical axis. The said roller arms shall carry grinding stones suspended onto the roller arms sleeves by means of bolts and lock nuts as shown in Figure 2. The Vertical roller mills are driven by transmissions connected to motors. The transmission could either be a gear motor directly connected to the motor and the mill centre shaft, or a transmission shaft driving the mill centre shaft by v-belts and it's self-driven by belt connected to the motor [5]. Power consumption, maintenance cost and Mean time between failures (MTBF) for two types of transmission will be compared with the total productivity of these mills. The productivity of the mill will be evaluated based on number of raw material, in kg grinded per hour [6, 7]. The study is conducted to standardize the entire number of grinding mills to either gearbox driven, or belt driven. Thereby standardizing the maintenance practice, spare part inventory and optimizing the output of the mills [8].

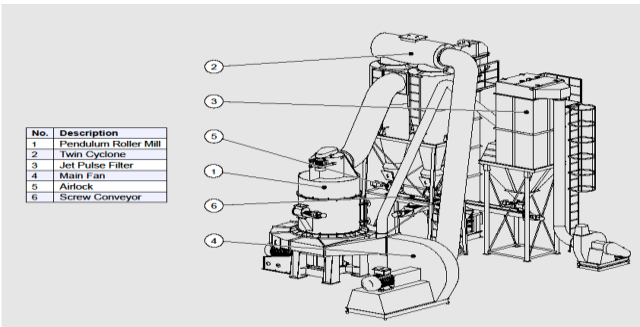

Fig. 2: Grinding plant layout

2.1. Parameters

The machine breakdown data had been obtained from the Computerized Maintenance Management System (CMMS) of the organization. Break down and maintenance record of Vector 1, (V1) mill had been identified to represent the belt driven VRM, while Vector 4, (V4) will represent the gearbox mill setup. The historical record of maintenance and break down is obtained from the history module, which details breakdown time, time to recover, waiting time for spare, waiting time for miscellaneous reasons, cost of repair, and man hours used to attend the breakdown and preventive maintenance work. The following Table 1 and 2 details the breakdown history for V1 and V4 respectively. The following legend is used to describe the type of maintenance activity carried out on the mills [9, 10];

CMP – Planned corrective maintenance
CMU – Unplanned maintenance
PM – Preventive maintenance

The waiting time is time incurred due to waiting for spare of particular repair activity, or the time incurred for repairing the machine at vendor site, or the time incurred while waiting for a particular tool to carry out a repair activity. The used stop time is the time used to actually carry out the repair works at the facility site. The total stoppage includes both the waiting time and used stop time, given by the formula below [11, 12, 13];

Actual Stoppage Time = Used Stop Time + Waiting Time

Table 1: Maintenance history for V1 mill

Job Executed Date (MM/DD/YY)	Work Order Key	Short Description.	Type	Waiting Time (Hr)	Used Stop Time (Hr)	Actual Stoppage Time (Hr)
01/06/16	014500	V1: Roller arm/Liner replacement	CMP	0	3	3
02/22/16	015173	V1: Belt drive cover damaged	CMP	0.75	0.5	1.25
03/08/16	015266	V1: Roller arm (R63) locker plate bolt broken	CMU	0	0.58	0.58
08/30/16	016657	V1: Roller arm jammed/Roller arm change	CMU	0	3	3
12/19/16	017414	V1: Center shaft - transmission shaft belt change	CMP	0	1.25	1.25
12/28/16	017504	V1: Mill jammed/ 1 unit scrapper broken	CMU	0	1	1
12/29/16	017518	V1: Center shaft pulley belts turned over	CMU	0	1.5	1.5
01/16/17	017640	V1: Transmission shaft (TS1) bottom pulley end broken	CMU	16	2	18
Total from 12/01/16 till 01/31/17				16.75	12.83	29.58

Table 2: Maintenance history for V4 mill

Job Executed Date (MM/DD/YY)	Work Order Key	Short Description.	Type	Waiting Time (Hr)	Used Stop Time (Hr)	Actual Stoppage Time (Hr)
12/04/15	014523	V4: Roller arm locker plate bolt broken/Roller arm (R21) change	CMU	4	4	8
12/08/15	014601	V4: Roller arm locker plate bolt broken	CMU	0	1	1
12/24/15	014674	V4: Center shaft service (Sleeve worn out)	CMU	112	13.25	125.25
02/19/16	015158	V4: R49 Locker plate bolt broken	CMU	0	0.33	0.33
03/09/16	015231	V4: Roller arm (R49) locker plate bolt broken	CMU	0	0.5	0.5
03/29/16	015448	V4: Roller arm (R49) locker plate bolt broken	CMU	0	1	1
04/06/16	015496	V4: R49 locker plate holding bolts loosen	CMU	0	0.33	0.33
05/07/16	015728	V4: Roller arm and liner change	CMP	0	5	5
06/25/16	016132	V4: Inverter 75kW (S/N 000001) error OC1	CMU	0	3	3
07/01/16	016185	V4: Roller arm locker plate bolt broken/stopper broken	CMU	0	5	5
08/20/16	008880	V4: MGB2 Gearbox Maintenance	PM	0	2.25	2.25
08/24/16	016602	V4: Mill motor (M211) short circuit	CMU	0	5	5
08/29/16	016602-01	V4: Mill inverter fan blower problem	CMU	0	1	1
09/17/16	016791	V4: M109 high amps/Change	CMP	0	3	3
10/13/16	016972	V4: Center shaft service/Roller arm & liner change	CMU	16	6	22
10/14/16	016694	V4: Inverter (DR-14) service	PM	0	1	1
01/04/17	017546	V4: Roller came loose from arm/Abnormal noise	CMU	0	2.25	2.25
Total from 12/01/15 till 01/31/17				128	53.91	181.91

Following are the productivity parameter that will be evaluated in this research. Each parameter represents different significance, and these parameters are widely influenced by the maintenance strategy implemented by organizations [14, 15].
MTBF = Total non-operational breakdown time / Number of failure occurrence
MTTR = Total non-operational repairing time / Number of failure occurrences
Availability = MTBF / (MTBF + MTTR)
Energy consumption/day = Total electricity (kWh) usage on a peak day, for 16 hours production operation.
Energy consumption/kg product = Total electricity (kWh) usage for production of 1 kg product.

Data grouped into the table shall provide early indication of most productive drive system. However, to further validate the data, and strengthen the conclusion the total operating cost of the modal mills will compared with respect to each other. It shall consist of the standard maintenance cost, spare part and consumable usage cost per year, and total estimated energy consumption per year.

3. Results and discussion

Table 3 below summarizes the MTBF and MTTR for both V1 and V4. The table represents the overall and failure specific MTBF and MTTR for both the drive types.

Table 3: MTBF and MTTR summary for Vector 1 and Vector 4

Failure	V1		V4	
	MTBF (Hr)	MTTR (Hr)	MTBF (Hr)	MTTR (Hr)
Overall/Mixed failure modes	698.30	3.70	362.49	11.91
Roller arm failures/Liner replacement	2805.00	3.00	2794.5	13.5
Roller arm locker plate bolt/scrapper failure	2807.21	0.79	699.70	2.30
Drive related failures	1685.17	6.83	-	-
Mill centre shaft failure/Service	-	-	2734.38	73.63
Variable frequency drive failure	-	-	2806.00	2.00
Overall/Mixed failure modes	698.30	3.70	362.49	11.91

The gear box driven Vector 4 mill has recorded a failure every 362.49 hour from the overall operating hours of 5616, it is approximately 1.3 failures every month for period of 1 year. While the belt driven Vector 1 mill has failed less frequently, with a recorded failure rate of 0.67 per month. V1 has an extended 335.81 operating hours between failures, as compared to V4. The overall MTBF for V1 and V4 are 698.30, and 362.49 hours respectively; both the mills require 3.70 and 11.91 hours to resume to normal operation after a failure occurrence. The higher time to recover to full operation for V4 might be due to the additional and more complex failure modes experienced by the gearbox driven mill. V4 mill requires approximately 3 times more time to recover to full operation.

Roller arm failures are associated with the operating speed, operating load and output of the respective mills. Higher outputs are achievable by increasing the mill operational speed; however it directly constitutes to increased load experienced by the mills. The V4 mill operates at 1400 rpm while V1 operates at 1200rpm, approximately 15% slower than V4. The grinding liner wear off rate is also proportional to this relation. V1 had recorded one roller arm failure between 01/12/15 and 31/01/17, and had its grinding liner replaced 2 times in that period. While, V4 had recorded two roller arm associated failures and, had its liner replaced 3 times in 61 weeks. The liner and roller arm replacement for V1 is done every 2805 hours, while for V4 the frequency is slightly higher, with a replacement job recorded every 2794.5 hours. Comparing the average production output of V4 against V1, this increase in frequency is considered negligible. However, the approximate 13.5 hours to recover the V4 mill after stoppage is 450% higher compared to V1 with a recorded MTTR of 3 hours only.

V1 had also encountered fewer problems with the roller and scrapper failure, V1 had only recorded 2 failures from operating 351 days. During the same period, V4 had encountered the same failure 5 times extra, totalling a 7 failure. It is the highest failure mode recorded by V4, with 1 failure for 699.70 of operating hour. These intermittent stoppages caused by such failure had accumulated 1.58, and 18.41 hour of stoppage time for V1 and V4 respectively. Due to the severity of damage caused by scrapper and roller arm locker plate failures, the time to recover the mills after stoppage is relatively high. V1 mill had a relatively low MTTR of 0.79, less than an hour. While V4 had recorded 2.30 hours to recover the machine to full operation after stoppage, MTTR for V4 is approximately 3 times higher than V1. This difference in the MTTR may be due to the high operational speed and load V4 mill undertaking.

V4 mill does experience few other failure modes, which is exclusion to the types of failure experienced by V1. The gearbox failure, VFD failure, and mill centre shaft failures are just a few to name. This high rate and additional failure modes are the direct consequences of a more complex construction of V4 as compared to V1. Additional components such as the gear motor, inverters, and couplings add to increased failure modes; More moving components, directly translates to more degree of freedom on the mechanism, and coupled with high load it increases the probability of failure in the mechanism.

The mill centre shaft failures experienced by V4 mill are non-existent in the belt driven V1 mill, this failure modes can be directly related to the different drive type used in both mills. While V1 has the load transmitted from the mill absorbed by the belt drive; V4 mill has no means of dissipating the load created by the roller arms hammering the grinding liner. Contrarily the gearbox allows the load transmitted from the motor to the centre shaft be amplified, if the coupling starts to fail or misaligned. These kinds of failure are hard to identify without specialized equipment and manpower. The V4 centre shaft had experienced failure twice, with a MTBF of 2734.38, which is approximately a failure occurrence every 6 month. Duration to repair V4 after the centre shaft failure consumes on average 73.63 hours, this is mainly because of the external work supplier involvement in replacing the centre shaft. The mill had to be dismantled and sent off to the external work supplier location to complete the repair work. Not only it consumes a considerable amount of time, it also priced heftily.

Apart from centre shaft failure the V4 mill also prone to VFD failures, experiencing failure related to VFD twice in the period on 5616 operating hours. It includes, circuit failure and inverter cooling fan failure. While these failures are not frequent, and maybe considered one-off occurrence, the time to recover the machine to operation is still considerably high. The V4 VFD failure would require 2 hours to rectify and resume back operation as normal. It may require more time for an unskilled and inexperienced group of staff to rectify the problem, which would be a difficult situation if is arise. Even though V1 mill motor is controlled by a VFD the, failure rate of this unit is not recorded in between the duration of the study. The lower operational speed and lower voltage motor may be the reason for uninterrupted operation of the VFD for V1.

Both the drive types have failure modes of its type. The belt driven V1 has experienced belt failure, transmission shaft failure, and minor belt cover damage, resulting in a total stoppage of 20.5 hours. It is a failure between 1685.17 hours operating the V1 mill, which requires approximately 6.83 hours to rectify these faults. Meanwhile, V4 has recorded no gearbox drive failure in between the same period. However, a gearbox drive might be vulnerable to gear failures such as local deformities, gear pitting, gear scuffing and scoring; or shaft failures such as run out, worn off or twist. The gearbox requires considerable amount of attention from experienced technical staff to ensure smooth operation without failures, with good maintenance practice the gear box can be utilized to the optimum service life of a gearbox. The belt driven V1 mill requires lesser attention as it does not involve metallic moving parts, as opposed to the gearbox driven V4 mill. The V4 mill requires the mill gearbox oil replaced at an interval of once every six months.

Table 4 represent the comparison between gearbox driven V4 mill against belt driven V1 mill in terms of energy consumption, and maintenance evaluation parameters. Availability of machineries is one of the key performance index used to evaluate maintenance effectiveness in the industry, higher availability indicates effective maintenance practice and higher throughput of a machine. Belt drive employed in vertical roller mills is less substantial to failures compared to gearbox drive. Belt drive system has a availability of 99.47% compared to 96.81%, most of the 2.66% difference in availability is due to the sporadic locker plate bolt and scrapper failure occurrence recorded in gear box driven, V4 mill. 43.75% of failure in V4 mill is caused by locker plate bolt damage, the higher rate of such failure is due to the type of drive employed in V4 mill. Meanwhile, V1 had only recorded 1 such failure during the same period.

Table 4: Comparison Gear Box Drive against Belt Drive Mill

Parameters	Gearbox driven	Belt driven
Energy consumption/day	231.36 kWh/day	218.40 kWh/day
Energy consumption/kg	2.014kWh/kg	3.295kWh/kg
Energy cost/kg	RM 0.76/kg	RM 1.25/kg
Energy cost for total output	RM 29,403.09	RM 28,672.96
MBTF	362.49 hour	698.30 hour
MTTR	11.91 hour	3.70 hour
Availability	96.81%	99.47%
Repair cost	RM 168,612.70	RM 41,151.30
Maintenance cost	RM 30,190.75	RM 30,387.50
Overhaul cost	RM 70,730.30	RM 49,959.30
Throughput	7.18 kg/hour	4.14 kg/hour

The overhaul of the entire mill together with their respective drive system differ by approximately 28% between gearbox drive and belt drive, with gearbox coupled mills be the more costlier units, with a recorded cost of RM 70,730.30. The failure rate of the belt drive coupled mill leading to overhaul of the entire mill is none form the year 2014. Thus, the belt drive mill has the highest lifespan, with least repair and overhaul cost. While its counterpart, the gearbox driven mill had recorded failures leading to overhaul nearly every year. This failure does not only incur maintenance expenses, but also results in loss of valuable production output.

Gearbox driven mill consumes considerably lower energy compared to belt driven mill, on average a gearbox driven mill consumes 231.36kWh per day, while belt driven mill consumes 218.40kwh per day, which is 12.96kwh higher per day. This lead to lower energy cost per kg of production output by gearbox driven mills. The gear box driven mill had consumed 78.62 MWh of energy producing 38,688.28kg of product, operating 5388.34 hours; While, belt driven, V1 mill had produced 22,938.37 kg of product, operating 152.33 hours longer than V4, consuming 76.25 MWh. Even, operating lower hours than gear box driven mill, the belt driven mill has consumed considerably higher amount of energy. The energy consumption of belt driven mill is 3.295kWh per kg of product produced, which is 1.281kWh higher than 2.014kWh/kg consumed by gearbox driven mill. This makes the gearbox driven mill favourite for energy saving greener production approach.

4. Conclusion

Figure 3 presents the operational cost breakdown for belt driven, and gearbox driven mills respectively. The V1 mill had consumed 41% of the total operational cost for maintenance, while V4 had used 33% higher for the maintenance of the mill. The energy cost of belt drive mill is higher by 16% compared with gearbox driven mill. While the maintenance cost for both the drive types are approximately equal, the maintenance cost for V4 is only 13% of the entire operational cost, while the it has taken up 30% of the total operational cost for belt driven mill.

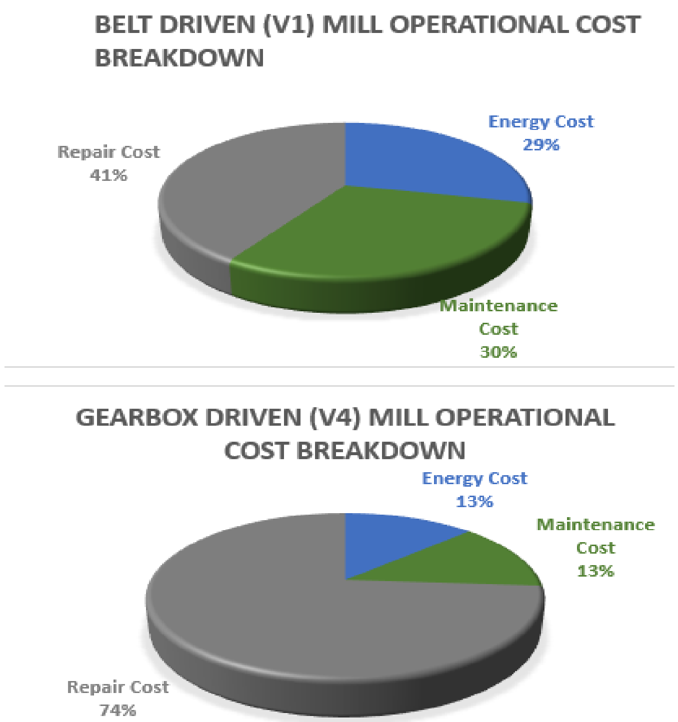

Fig. 3: V1 and V4 Operational cost breakdown

The figure indicates higher failure rate of gearbox driven mill, thus higher breakdown maintenance cost for V4 mill, which a poor operational strategy is going forward. The breakdown frequency and repair cost of equipment should be kept as minimal as possible, while some equipment design flaws could be rectified to improve the reliability of the equipment, a more conventional method is required when such efforts are proven to be futile.

The higher energy consumption of belt driven mills could be improved by mean of replacing the existing motor with a more energy saving motors and improving the preventive maintenance practice, to avoid machine condition such as belt slack which can lead to energy wastage. Considering the overall cost distribution of both the drive type, the belt driven mill id found to be more economical and reliable compared to the gearbox driven mill.

Acknowledgement

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References

[1] Wheeldon, M., Galk, J., & Wirth, K.-E. (2015). Investigation of the comminution process in pendular roller mills. International Journal of Mineral Processing, 136(0), 26-31.
[2] Wes Cash, N. C. (2012). What is Lubrication. Machinery Lubrication. 2015, from http://www.machinerylubrication.com/Read/28766/what-is-lubrication
[3] P. H. Southwell. (1960). Mechanical, Electrical or Hydraulic Transmission? Department of Engineering Science, Ontario Agricultural College, Guelph, Ontario.
[4] Berna Balta, Fazil O. Sonmez, & Abdulkadir Cengiz. (2015). Speed losses in V-ribbed belt drives. Mechanism and Machine Theory, Volume 86, pages 1 -14.
[5] Schwamborn, K. H., Vienken, J., Galk, J., Plihal, G., Teriete, W., Simons, T., & Bianga, N. (2011). Pendulum mill: Google Patents.
[6] M. M. Chen, "Fine grinding roller mill," ed: Google Patents, 2010.
[7] M. M. Chen, "Fine grinding roller mill," 2011.
[8] Williams, R. M. (2002). Grinding apparatus with vertical static separators: Google Patents.
[9] Holton, D. L., & Verma, A. (2009). Work in progress - Using the AC/DC circuits concept inventory to inform the design of a circuit simulation and instructional strategy. 39th ASEE/IEEE Frontiers in Education Conference, San Antonio, TX.
[10] Holz, K., & Balders, R. (2011, 22-26 May 2011). Lubrication and maintenance for key machines in the cement industry. Paper presented at the Cement Industry Technical Conference, 2011 IEEE-IAS/PCA 53rd.
[11] Ogunfunmi, T., & Rahman, M. (2010). A concept inventory for an electric circuits course: Rationale and fundamental topics. 2010 IEEE International Symposium on Circuits and Systems: Nano-Bio Circuit Fabrics and Systems, ISCAS 2010, Paris, 2804-2807.
[12] Prince, M. J., Vigeant, M. A., & Nottis, K. (2010). Assessing misconceptions of undergraduate engineering students in the thermal sciences. International Journal of Engineering Education, 26(4), 880-890.
[13] Sanayi, C. M. Pendulum Roller Mills. 2015, from http://caglayanmakina.com.tr/en/?sayfa=urunler&kat=42&urun=42
[14] Smaill, C. R., Rowe, G. B., Godfrey, E., & Paton, R. O. (2011). An investigation into the understanding and skills of first-year electrical engineering students. IEEE Transactions of Education, 55(1), 29-35.
[15] Streveler, R., Geist, M., Ammerman, R., Sulzbach, C., Miller, R., Olds, B., & Nelson, M. (2006). Identifying and investigating difficult concepts in engineering mechanics and electric circuits. 113th Annual ASEE Conference and Exposition, 2006, Chicago, IL.