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Lean Energy Consideration of a Nigerian Sawmill Facility

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Abstract

Leanness can be defined as minimization of waste. Waste depletes resources but does not have any improvement on the values of the products. It can occur in many forms and in many places. Lean methods help to reduce waste. Waste can be minimised by isolating and eliminating those activities that have no value adding effect on products. Lean programs create a cultural and people-oriented transformation by educating entire organizations on how to identify hidden wastes and empowering each employee to enhance the quality of production. Lean energy can be achieved by exposing the aspects that contribute to the supplementary energy component. This work considers isolating the energy wasting components of machines used in log processing by analyzing the entire energy use pattern. In the log processing industry sector, energy is consumed for a wide range of activities such as sawing, lighting, saw sharpening and other maintenance activities. The sawmill facility under investigation is the electric motor. The entire machines used in the production process have electric motors as their prime mover. The power rating of the electrical devices and capacity of each unit were collected from the personnel in charge. The production processes were monitored and measurements of necessary parameters were taken with the aid of the following instruments: Wattmeter, digital laser Tachometer, stop watch and tape; data were recorded for weeks depending on the size of the site being considered. The study showed that a 10hp motor replacement would likely perform the sawmilling operation on the band saws more efficiently.

Keywords: Wastes, Resources, Energy, Timber log, Organization

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INTRODUCTION

Leanness can be defined as the minimization of waste. Waste utilizes resources but does not add value to the product. It takes many forms and can be found at any time and in any place. Different forms of wastes are: complexity, labour, overproduction, space, energy, defects, materials, time, and transport (Gopalakrishnan *et al*., 2012).

Lean manufacturing (a branch of leanness or waste minimisation) or lean transformation is a means of doing more with less input or the input remains the same and the output increases. Lean manufacturing has transformed, over time, through a dramatic evolution from a vague and secluded thought to a conventional tactic all through the industrial manufacturing supply chain (Sciortino *et al*., 2009). Lean methods help in reducing wastes involved with the "eight deadly wastes" such as: overproduction, inventory, transportation, motion, defects, over-processing, under-utilized people, and waiting.

Waste minimisation can be achieved by the isolation and elimination of those activities that do not add value to the product being made. Continuous improvements in the areas of quality improvement, scheduling of resources, and productivity enhancement play a vital role in lean manufacturing (Gopalakrishnan *et al*., 2012). At their core, successful lean programs create a cultural and people-oriented transformation by educating entire organisations on how to identify hidden wastes and empower each employee to enhance the quality of production (Sciortino *et al*., 2009).

The non-allowable waste in the manufacturing environment is mostly visible, such as waste due to the piling of inventory, improper manpower and machine scheduling, process waste, and many other commonly observed practices in the industrial environment (Gopalakrishnan *et al*., 2012). However, opportunities for lean energy are not as obvious as in lean manufacturing, although analysis of data may reveal hidden non-essential energy consumption (NEEC). Lean energy can be achieved by uncovering aspects that contribute to the nonessential energy component.

According to Sciortino *et al*. (2009), 60 percent of senior executives at large, multinational U.S. manufacturing companies believe that oil and energy prices are the leading barrier to company growth. Benchmarking therefore, plays an important role in unveiling the possibility of any NEEC. It is likely that operations are already energy efficient, without any NEEC. However, it is necessary to first measure energy use before finding ways to control it. If this type of approach is practiced by an organization on its electrically driven machinery for example, it is likely to make every effort in checking every motor to know their status to ascertain how far away it is operating from the theoretical energy consumption value. If the gap is small, then the motor can be considered to be lean in terms of its energy usage, and vice versa. If the motor is not lean in terms of the energy usage, then effort should be made to making it as lean as possible.

This work identifies and isolates area(s) where energy use is uneconomical and consequently devises method of curtailing such wastage of energy and thereby improving energy efficiency with a cost-benefit.

Saw Mill Facilities

Facilities available in sawmills depend chiefly on the complexity of the sawmill. A basic saw mill should have a log yard to receive and store the timber log awaiting processing; band mill for cutting the log into slabs for sale or for further processing; re-sawing machine (circular machine) for re sawing slabs to various plank sizes as dictated by the market or as requested by customers and the storage facility for products waiting for delivery or sale.

Energy Saving Potentials in a Typical Sawmill

Energy savings implementation can have significant benefits. Being the largest end users of energy in a typical sawmill, the electrical motors become obvious candidates for energy analysis and determination of possible energy savings potential. Although energy is used for other purposes such as lightings, fans, refrigerators, radios among others, the amount is quite negligible compared with what electric motors consume coupled with the fact that majority of the sawmills in the case study area do not use them. In the case of lightings which may be significant, sawmills in the case study area operate during the day only, thereby eliminating the need for accounting for lighting energy need. An important distinction between a motor operation at sawmill versus other manufacturing facilities is the rigorous working environment at sawmills under which the equipment operates. The equipment, (and thus the electrical motors), undergo significant lifetime wear (US EIA, 1995).

RESEARCH METHODOLOGY

Method

The power rating of the electrical devices and capacity of each unit were collected from the personnel in charge. The production processes were monitored and data collected for weeks depending on the size of the site being considered. The time it took to complete each process was also recorded.

The electrical energy used by the log processing machines was predicted by using a formula developed by Rajput (2001). The electrical energy usage by equipment was obtained as the product of the rated power of each motor of the plant or equipment and the number of hours of operation. A motor efficiency of 80% was assumed to compute the electrical inputs (Rajput, 2001). Mathematically, the formula is given as:

$$E_P = \eta P t \tag{1}$$

Where, E_P is the electrical energy consumed in kWh, P is the rated power of the motor in kW, t is the time of operation in hours and η is the efficiency of the motor or power factor usually taken as 80% or 0.8.

The mean (root mean square) voltage, current, power factor, speed, phase angle and time for each reading were obtained at each sawmill for lumber cut on the band saw and are presented in the next section. The data were obtained during the cutting operation. No measurement was taken when the band saw was returning. The number of lumber cuts per log depended on the specification of the customer and the size of the log.

All sawmills visited made use of old standard efficiency motors, which could be replaced with newer premium efficiency ones. The electric motors used on all the band saws were standard efficiency motors which were older than 40 years. Also, motor name plate data were not available for any of the band saw motors.

Motor master+ 4.1 (WSU Cooperative Extension Energy Program, (2013)) is a software containing an up-to-date database of thousands of existing motors of various specification from different manufacturers, and it was used to locate more energy efficient premium efficiency motors which can replace the old standard efficiency motors used in the sawmills visited

The motor master software recognises four speed grades of motors, which are: 900rpm, 1200rpm, 1800rpm, 3600rpm. The electric motors in the band saws used in the sawmills visited were mostly used at a speed close to 900rpm, thus the alternative motors selected for better efficiency will best be in the 900rpm rating.

All the motors had a size of 25 hp, and the alternative sought were in the general-purpose category. The grades of voltage rating available in motor master 4.1+ are: 200, 208, 220, 230, 440, 460, etc.

Apparatus

The apparatus used are: Wattmeter to measure the electrical energy used, Digital Laser Tachometer to obtain the speed of the motor during operation on a given log, Stop Watch for measuring production time and Measuring Tape to take the diameters of the timber log.

RESULTS AND DISCUSSION

The major and easiest of all factors that can be modified in energy efficiency implementation are the drive motor operating characteristics especially the size of motor. It is therefore imperative to source for an alternative electric motor that will have every feature as in the existing electric motors in the sawmills that would consume lean energy, i.e. electric motor with better energy efficiency. This can be made easy with the Motormaster+ software.

In this section, the parameters of electric motors installed on the band mill of some selected sawmills in the study area were used for the analysis and presented. Four sawmills were used for the analysis and the result are presented below.

Measured Data

Tables 1 to 4 contain the data for the Voltages (V), Currents (I) and Power Factors (P.F.) of electric motors of band mill machines of the four selected sawmills in the study area. These data will enable us to determine the consumed energy of the machine so as to be able to compare the energy consumed for specific operation with the exact energy required for the operation. Further analysis for the comparation is presented in Tables 5 to 8.

Sawmill 1

As presented in Table 1

Motor speed and type: 920 rpm and Totally Enclosed Fan-Cooled (TEFC) respectively.

Table 1: Data measured at Sawmill 1

V(volt)	205.3	199.9	199.2	206.1	199.7	200	200	199.5	-	-
I(Amp.)	16.6	19.7	26.6	24.0	29.3	29.7	28.4	26.8	26.0	30.5
P.F.	0.88	0.70	0.0041	0.82	0.76	0.80	0.77	0.76	0.80	-

Sawmill 2

As presented in Table 2

Motor speed and type: 865rpm and Open Drip-Proof (ODP) respectively.

Table 2: Data measured at Sawmill 2

V(volt)	202.1	196.0	203.1	208.6	203.4	201	205	198	-	-
I(Amp.)	17.5	20.2	23.3	28.6	25.3	24.1	27.8	28.7	25.5	22.6
PF	0.88	0.88	0.87	0.70	0.71	0.70	0.72	0.003	0.0031	0.70

Sawmill 3

As presented in Table 3

Motor speed and type: 888 rpm and Open Drip-Proof (ODP) respectively.

Table 3: Data measured at Sawmill 3

V(v)	200.0	203.6	198.5	199.8	207.1	203	200	202.6	-	-
I(A)	18.2	20.1	23.2	21.5	26.3	29.2	30.1	27.8	25.3	27.9
PF	0.88	0.70	0.75	0.80	0.84	0.70	0.76	0.77	0.82	-

Sawmill 4
As presented in Table 4
Motor speed and type: 850 rpm and Totally Enclosed Fan-Cooled (TEFC) respectively.

Table 4: Data measured at Sawmill 4

V(v)	204.2	199.3	204.7	203.1	199.7	201.0	204.9	198.9	-	-
I(A)	18.6	19.4	23.5	26.3	27.3	28.1	25.6	27.2	30.1	22.4
PF	0.72	0.77	0.042	0.76	0.68	0.80	0.70	0.70	0.72	-

***Data* Analysis**
The full load efficiency of a TEFC motor, from the standard Table (USDoE, 1993) is 87.9%, thus the input power at full rated load from equation (i) (USDoE, 2014a)

$$P_r = HP \times \frac{746}{\eta_R} \qquad \text{Eq. (2)}$$

is, $P_r = 25 \times \frac{746}{0.879} = 21217.3W = 21.22kW$

Similarly, the full load efficiency of an ODP motor, from the standard Table is 88.3%, thus the input power at full rated load is:

$$P_r = 25 \times \frac{746}{0.883} = 21121.2W = 21.12kW$$

All efficiency data in Tables 5 to 8 were interpolated from the Standard Table (USDoE, 1993)

The load, power and efficiency calculated for the data obtained from sawmill 1, 2, 3 and 4 are shown in Tables 5, 6, 7 and 8 respectively. Below is the sample calculation for sawmill 1 which is applicable to other considered sawmills.

The sample calculation of the power, load and efficiency of the column 4 in Table 1 is given below; values in other columns are similarly calculated.

V=206.1V; I= 24A; P.F. = 0.82; HP = motor size = 25hp

$$P(W) = v \times I \times PF \times \sqrt{3} \qquad (3)$$

$$P(W) = v \times I \times PF \times \sqrt{3} = 206.1 \times 24 \times 0.82 \times \sqrt{3} = 7025.28W$$

$\eta_R =$ efficiency at 100% load with TEFC motor type $=$ 87.9% (Motor master + 4.1)

From eq. 2,

$$P_r = HP \times \frac{746}{\eta_R} = 25 \times \frac{746}{0.879} = 21217.29W$$

$$\%\text{ of full load L,} = \frac{7025.28}{21217.29} \times 100\% = 33.11\%$$

From Standard Table, for a 25hp TEFC motor; efficiency at 25% load = 78.6; efficiency at 50% load= 86.8. Using linear interpolation, the efficiency at 33.11% load is given by

$$eff_{33.11} = \frac{l - l_1}{l_2 - l_1} \times \left(eff_{50} - eff_{25}\right) + eff_{25} = \frac{33.11 - 25}{50 - 25} \times \left(86.8 - 78.6\right) + 78.6 = 81.26\%$$

Table 5: Spreadsheet Data with Calculated Load, Power and Efficiency for Sawmill 1

V(volt)	205.3	199.9	199.2	206.1	199.7	200	200	199.5
I(amps)	16.6	19.7	26.6	24	29.3	29.7	28.4	26.8
P.F.	0.88	0.7	0.0041	0.82	0.76	0.8	0.77	0.76
P(W)	5194.5	4774.6	37.63	7025.3	7702.3	8230.7	7575.3	7038.0
Fraction of full load	0.2448	0.2250	0.001773	0.3311	0.3630	0.3879	0.3570	0.3317
% of full load (L)	24.482	22.50	0.1773	33.11	36.30	38.79	35.70	33.171
efficiency	<78.6	<78.6	<78.6	81.26	83.95	83.12	82.11	81.28

Table 6: Spreadsheet Data with Calculated Load, Power and Efficiency for Sawmill 2

V(volt)	202.1	196	203.1	208.6	203.4	201	205	198
I(amps)	17.5	20.2	23.3	28.6	25.3	24.1	27.8	28.7
P.F.	0.88	0.88	0.87	0.7	0.71	0.7	0.72	0.003
P(W)	5390.7	6034.6	7130.9	7233.3	6328.3	5873.1	7107.1	29.528
Fraction of full load	0.2552	0.2857	0.3376	0.3425	0.2996	0.2781	0.3365	0.0014
% of full load load (L)	25.522	28.57	33.76	34.25	29.96	27.81	33.65	0.1398
efficiency	83.11	83.73	84.79	84.89	84.01	83.57	84.76	Inv

Table 7: Spreadsheet Data with Calculated Load, Power and Efficiency

V(volt)	200	203.6	198.5	199.8	207.1	203	200	202.6
I(amps)	18.2	20.1	23.2	21.5	26.3	29.2	30.1	27.8
P.F.	0.85	0.7	0.75	0.8	0.84	0.7	0.76	0.77
P(W)	5359.0	4961.7	5982.3	5952.3	7924.6	7186.8	7924.5	7511.7
Fraction of full load load	0.2537	0.2349	0.2832	0.2818	0.3752	0.3403	0.3752	0.3556
%of full load (L)	25.37	23.49	28.32	28.18	37.52	34.03	37.52	35.56
efficiency	83.08	<83.0	83.68	83.65	85.55	84.84	85.55	85.15

Table 8: Spreadsheet Data with Calculated Load, Power and Efficiency for Sawmill 24

V(volt)	204.2	199.3	204.7	203.1	199.7	201	204.9	198.9
I(amps)	18.6	19.4	23.5	26.3	27.3	28.1	25.6	27.2
P.F.	0.72	0.77	0.042	0.76	0.68	0.8	0.7	0.7
P(W)	4736.5	5156.6	349.94	7031.4	6421.1	7826.2	6359.8	6559.3
Fraction of full load	0.2232	0.2430	0.01649	0.3314	0.3026	0.3689	0.2997	0.3091
% of full load (L)	22.32	24.30	1.649	33.14	30.26	36.89	29.97	30.91
efficiency	<78.6	<78.6	Inv	81.27	80.33	82.5	80.24	80.54

According to USDoE (2014a), motors typically operate at their highest efficiency when loaded to between 70% and 80% of full-load. These sawmills had an average load less than 50%, thus they were not operating at their maximum efficiency. It would be more efficient to replace the motors with motors using smaller horsepower ratings, so that the machine will operate nearer optimum load, and thus, at maximum. Thus, the motors can operate close to the 70-80% load range and still perform the required operation as before. The higher the horse power rating of a motor the higher the energy consumed.

Alternative Motor Selection

According to USDoE, (2014a), motors typically operate at their highest efficiency when loaded to about 70 to 80% of full-load. All the band saw motors in all sawmills visited operate at an average load less than 50% as shown in Tables 5 to 8. This implies that the motors are grossly oversized (under-loaded) and hence they consume more energy than requires (necessary).

Under-loaded motors are inefficient with regards to energy consumption, and they operate at lower power factor, which in turn results in increased electrical distribution losses. Replacing under-loaded motors with the correctly sized motor raises efficiency and improves power factor (DoE, 1991). This will in turn lead to reduction in energy required to process the timber log.

In other words, a smaller motor would be more efficient for the task. The optimum motor size (in horsepower) for a smaller replacement motor which will perform the sawmilling operation more effectively can be determined as follows:

The smallest efficiency for any motor (ODP or TEFC) operating at 50% and above of full load, with a size less than 25hp operating, and in the 900 rpm grade is 84.8% (from the standard Table (USDoE, 1993), while the maximum efficiency for such motors is 88.9%. Thus, the efficiency values essentially do not vary much above 50% of full load for old standard efficiency motors.

According to USDoE (2014),

$$L = \frac{P}{p_r}$$

From eq. (i), $L = \dfrac{P}{\dfrac{HP \times 746}{\eta}} = \dfrac{P \times \eta}{HP \times 746}$ and $\therefore HP = \dfrac{P \times \eta}{L \times 746}$

HP = required optimum horsepower rating, η = average efficiency, L = output power as % of full load, P = measured three phase power i.e. input power (kW), P_r = input power at full rated load (kW) (as obtained from eq. (i))

The alternative motors available, as seen in Motormaster+ come in the following sizes: 1.5hp, 2hp, 3hp, 5hp, 7.5hp, 10hp, 15hp, 20hp, 25hp, 30hp, 40hp, 50hp, and so on. The efficiency reaches a maximum at about 75% load (USDoE, 2014b), thus, as a rough estimate, the required horsepower rating for correct motor that should be installed in all sawmill to ensure energy management is thus calculated as follow:

i. For sawmill 1; $HP = 6790.1 \times \frac{0.8442}{0.75 \times 746} = 10.25 \approx 10hp$

ii. For sawmill 2; $HP = 6442.3 \times \frac{0.8412}{0.75 \times 746} = 9.69 \approx 10hp$

iii. For sawmill 3; $HP = 6600.3 \times \frac{0.8431}{0.75 \times 746} = 9.94 \approx 10hp$

iv. For sawmill 4; $HP = 6298.7 \times \frac{0.8030}{0.75 \times 746} = 9.04$

The closest to all these HPs on the Motormaster catalogue is 10hp

CONCLUSION

A 10hp replacement motor would likely perform the sawmilling operation on these band saws more efficiently. However, it cannot be ascertained whether such motors were intentionally oversized by the manufacturers to compensate for considerations such as the starting torque or other factors in operation, but under normal working conditions, the sizes calculated above will be more effective, and it will serve as a cheaper (relative to energy) alternative. The average voltage during the operation of all the four sawmills as calculated above are greater than 200V, but less than 208V, thus the alternative motor to be selected for better efficiency will be in the 208V rating.

Using Motormaster+ software, the alternative motors available for sawmill 1 and sawmill 4 motors, using a catalog voltage of 208, speed grade of 900 rpm, and size of 25hp and 10hp Totally Enclosed Fan-Cooled (TEFC), NEMA design B.

Also, using the Motormaster+ software, the alternative available for sawmill 3 and sawmill 2 motor, using a catalog voltage of 208, speed grade of 900 rpm, and size of 25hp open drip-proof (ODP) and NEMA Design B.

RECOMMENDATIONS

i. Experience gained in this work revealed that it is either that there is no regulatory policy on energy use in sawmills in Nigeria or there is no machinery in place to enforce the policies. Players in this sector do what they like with regard to energy use. It is therefore recommended that the government should put some policies in place to check wasteful use of energy. It is immaterial whether the person or group of people concerned has money to pay for energy they use or not. A wasteful use of energy by some people is certainly a denial of the use of same energy by other people. It should be recognised that the generation of energy have some adverse effect on the environment, therefore any policy that will minimise (optimise) the energy use is also a way of improving the environment.

ii. It is also recommended that an agency should be put in place to supervise the establishment of sawmill in Nigeria. This agency should ensure that appropriate electric motor (10hp) that will match the power requirement of an operation should be installed.

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