DEVELOPMENT OF EFFECTIVE ENERGY MONITORING AND TARGETING SYSTEM (EEMTS) FOR A FOUNDRY USING STATISTICAL MODEL TECHNIQUE

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Abstract Effective energy monitoring and targeting system is needed for any industry to reduce energy cost through improved energy efficiency and energy control. Most widely used standard is the specific energy consumption (SEC) and often it is considered as an energy level indicator. But it is not a sensitive factor and also not suitable for energy monitoring and control. In this paper a statistical model is described by looking at the history of energy use to production. The objective of this study is to propose a statistical model for energy monitoring and control using CUSUM (CUMulative SUM of difference) technique. A foundry using induction furnaces is selected for this case study and its energy consumption data is used to verify the statistical model. The proposed EEMTS model has been found to be an effective tool and it provides accurate information on energy saving possibilities.

Key words: Energy monitoring and targeting, specific energy consumption, CUSUM, energy savings

INTRODUCTION

Energy monitoring and targeting is primarily a management technique that enables industries to control energy consumption accurately [Henson J. L, Stott M. D.1988]. Monitoring and targeting is an approach in energy management to eliminate waste, reduce current level of energy use and improve the existing operating procedures [Tony Wilson, 1992]. Monitoring and target setting (M&T) is an activity, which uses information on energy consumption as a basis for the control and management of energy use. It essentially combines the principles of energy use and statistics. Monitoring is essentially aimed at preserving an established pattern. Target setting is the identification of energy consumption level, which is desirable as a management objective to work towards [Energy Management Handbook, 1999]. CUSUM charts are often used instead of the standard Shewart charts when detection of small changes in a process parameter is important. A CUSUM chart is a plot of cumulative sequential differences between each data point and process average over time [Thomas P Ryan, 2000]. CUSUM is a technique to see through random scatter and to detect changes in the pattern in monitoring the energy consumption and helps target setting [Words Worth, 1997].

The review of published information highlights the importance of energy monitoring and targeting in any industry to assess the energy consumption pattern over the period. Some papers indicate the use of CUSUM graph for effective identification in process change. Further, many of them restricted their attention to CUSUM procedures for the study of energy use information and not for monitoring and targeting energy consumption.

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It was found that the melting section of a foundry consumes maximum electrical energy and it is up to 60-75% of total energy consumption. Therefore, melting section is considered as a critical department and this paper explains the M&T system for it. Energy consumption by furnaces is recorded on daily basis and this model makes use of CUSUM statistical technique for monitoring and targeting.

METHODOLOGY

Regression Model Approach

The energy required to melt the material is $H_{1-2} = m [C_p (T_c-T_1)+L+C_p (T_2-T_c)]$ where T_c is the temperature at which phase change occurs (melting point), 'm' is the mass of metal, 'C_p' is the specific heat of metal and T_1 and T_2 are initial and final temperature of the melting process. For a melting process, which produces consistent product, T_1 and T_2 do not vary. If the product is made from the same material, C_P and latent heat (L) do not change either. The only possible factor, which will vary, is the mass of material processed and hence the graph of energy use against mass of material

processed forms a straight-line [Tripathi S. C. 1991].
The effect of increased production on energy consumption can be represented by a regression equation. But availability of the plant data on an annual basis severely limits the development of such relationship. This can be overcome if data is developed for narrow time interval, like quarter of year, monthly and daily [Khosla S.M.1996]. The justification for such an approach, however is provided by selecting data for the particular period in a year that will provide best historical performance information i.e. positive relationship between energy and production which is measured by R^2 value the correlation coefficient. The higher value of R^2 indicates best fit between energy consumption to production of castings.

The equation of the straight line is

$y = mx+c$ -------------1

Where y: electrical energy consumption in kWhr
x: production castings in tons per day
m: represents slope of the line (The amount of energy required to melt each additional unit of production)
c: Constant value and the intercept of the y-axis (The energy that will still be required even if production was reduced to zero)

Melting section of the cast iron foundry has three induction furnaces each having capacity 3.5, 1 and 0.8 tons respectively. Total electrical energy in kWh and total molten metal production in tons are collected from these three electric furnaces of various months in year 2000. The total electric energy consumption data and molten metal production data are used to develop regression equation of the base line (best fit) based on one month data (based on best historical performance information) selected from the Table 1 of year 2000 of electrical melting furnaces using Excel spread sheet and is shown in the fig. 1 and the equation is given by

$y_{n0} = 512.x+3296.1$ ------------2

where n0 - for year 2000

and R^2 = 0.8541 (coefficient of determination)

Table 1: Performance data of year 2000

Month	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**
R^2	0.49	0.72	0.82	0.67	0.25	0.85
Month	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
R^2	0.681	0.75	0.572	0.82	0.69	0.72

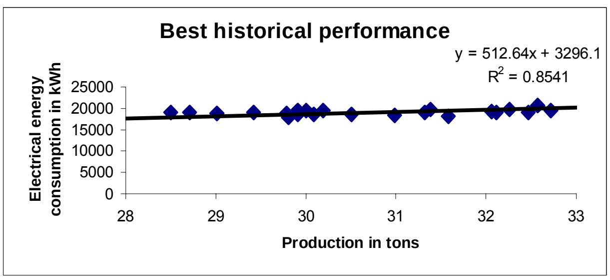

Fig. 1 Best-fit line of year 2000 to predict energy consumption

CUSUM Calculation

The data to be monitored for energy saving evaluation for year2001 are shown in the Table 2. CUSUM plots cumulative difference between predicted and actual energy use against time.

Table 2: Electrical energy and production one-month data of induction furnaces year 2001 (melting section)

Day	**Production in tons (molten metal) from melting furnaces(2001)**	**Total Actual Electrical energy consumption in kWh from melting furnaces (2001)**
1	26.335	17390
2	28.783	18150
3	23.035	14160
4	27.765	15990
5	29.105	18810
6	27.726	17000
7	27.002	16400
8	26.042	15510
9	22.551	14050
10	25.155	15470
11	26.023	17280
12	28.004	17620
13	26.707	16970
14	26.140	16660
15	27.824	16770
16	24.549	14600
17	25.551	17370
18	26.280	16350
19	24.654	16080
20	26.959	18460
21	28.124	17860
22	29.352	18150
23	27.785	17070
24	28.699	17120
25	28.395	19000
26	27.555	17230

Formulation of CUSUM Statistical Graph

CUSUM chart uses equal interval time series data i.e. information of the same kind gathered at the same time of each day, week, month, and organised in the same time order as it was measured.

$Df_{n1}=(Ai-y_{no}i)$ --------------2

$Qm_{n1}= \sum_{i=1}^{n} Df_{n1}i$ --------------3

Where $A_{n1}i$: Actual value of total electrical energy used in kWhr by furnaces at i^{th} observation for year 2001

$y_{no}i$: Predicted value of energy used in kWh at i^{th} observation from best historical energy use to production and is used to monitor the future energy consumption in melting furnaces

x_{o1}: Production in tons (molten metal) for the year 2001

Df_{n1}= CUSUM difference in kWh

Qm_{n1}: Sum of CUSUM difference in kWh

Non-productive energy used based on best fit is given by

$pc_{n1} = ci/yi_{n0}i$ -------------------------4

ci = Non productive energy use in kWh at i^{th} observation

pc_{n1}= percentage non productive energy use

The CUSUM value is useful in identifying the changes in energy consumption pattern. The Table 3 shows the CUSUM calculation performed on data collected from the induction furnaces.

Table 3 CUSUM calculations performed on data

Days	Production in tons (molten metal) x_{o1}	Electrical energy consumption in kWh			CUSUM electrical Energy in kWh Qm_{n1}	Non-productive energy use in % pc_{n1}
		Actual A_{n1}	Predicted y_{n0}	Difference Df_{n1}		
1	26.335	17390	16796.37	593.6256	593.6256	19.6
2	28.783	18150	18051.32	98.68288	692.30848	18.25
3	23.035	14160	15104.66	-944.662	-252.35392	21.82
4	27.765	15990	17529.45	-1539.45	-1791.80352	18.8
5	29.105	18810	18216.39	593.6128	-1198.19072	18.0
6	27.726	17000	17509.46	-509.457	-1707.64736	18.8
7	27.002	16400	17138.31	-738.305	-2445.95264	19.23
8	26.042	15510	16646.17	-1136.17	-3582.12352	19.8
9	22.551	14050	14856.54	-806.545	-4388.66816	22.18
10	25.155	15470	16191.46	-721.459	-5110.12736	20.35
11	26.023	17280	16636.43	643.5693	-4466.55808	19.80
12	28.004	17620	17651.97	-31.9706	-4498.52864	18.67
13	26.707	16970	16987.08	-17.0765	-4515.60512	19.41
14	26.140	16660	16696.41	-36.4096	-4552.01472	19.74
15	27.824	16770	17559.7	-789.695	-5341.71008	18.77
16	24.549	14600	15880.8	-1280.8	-6622.50944	20.17
17	25.551	17370	16394.46	975.5354	-5646.97408	20.12
18	26.280	16350	16768.18	-418.179	-6065.15328	19.65
19	24.654	16080	15934.63	145.3734	-5919.77984	20.68
20	26.959	18460	17116.26	1343.738	-4576.0416	19.25
21	28.124	17860	17713.49	146.5126	-4429.52896	18.61
22	29.352	18150	18343.01	-193.009	-4622.53824	17.96
23	27.785	17070	17539.7	-469.702	-5092.24064	18.79
24	28.699	17120	18008.26	-888.255	-5980.496	18.30
25	28.395	19000	17852.41	1147.587	-4832.9088	18.46
26	27.555	17230	17421.8	-191.795	-5024.704	18.91

CUSUM Control Chart

CUSUM is better at detecting small shifts of the process mean than standard control charts and provides an earlier indication of whether improvement efforts are succeeding or not. This is an important part of the performance evaluation measures used in continuous improvement efforts [Thomas P Ryan, 2000]. A CUSUM chart plots the cumulative sequential difference of each data point and process average over time. CUSUM chart procedure on controlling the data is given by

$$Nm = \sum_{i=1}^{m} (Df_{n1}i - k) \quad \text{----------------5}$$

Where k: Reference value

m: Number of days

i: Observation number

Df_{n1} : CUSUM difference value in kWh

Nm : Value in electrical energy kWh

$$Cm = \max [0, Cmi-1 + Df_{n1}i_i - k) \quad \text{------------6}$$

In the present problem k=0 as there is no change in μ value for the selected month used for verification

$$Cm = \max [0, Cmi-1 + Df_{n1}i - 0) \quad \text{-----------7}$$

Where Cm: One sided value in electrical energy kWh to be plotted for process control

Decision control limit [Thomas P Ryan, 2000] =

$h\sigma = 5*0.73$ -----8

Where σ: Standard deviation (0.73) for the above data

Decision control limit value obtained is 3.65.

The CUSUM data from previous calculation is used here for the process control plotting. For simplification purpose all the values are converted in to fraction value (by dividing 1000)

The Table 4 shows the CUSUM control calculation performed on data for the selected monthly data.

Table 4 CUSUM control chart calculation

m	Df_{n1}	$Df_{n1}i$ -k	Nm	Cm
1	0.59	0.59	0.59	0.59
2	0.09	0.09	0.69	0.68
3	-0.94	-0.94	-0.25	0
4	-1.54	-1.54	-1.80	0
5	0.59	0.59	-1.20	0.59
6	-0.51	-0.51	-1.71	0.08
7	-0.74	-0.74	-2.45	0
8	-1.14	-1.14	-3.59	0
9	-0.81	-0.81	-4.39	0
10	-0.72	-0.72	-5.11	0
11	0.64	0.64	-4.47	0.64
12	-0.03	-0.03	-4.50	0.61
13	-0.02	-0.02	-4.52	0.59
14	-0.04	-0.04	-4.56	0.55
15	-0.79	-0.79	-5.34	0
16	-1.28	-1.28	-6.62	0
17	0.98	0.98	-5.65	0.98
18	-0.42	-0.42	-6.01	0.56
19	0.15	0.15	-5.92	0.71
20	1.34	1.34	-4.58	2.045
21	0.15	0.15	-4.43	2.195
22	-0.19	-0.19	-4.62	2.005
23	-0.47	-0.47	-5.09	1.535
24	-0.89	-0.89	-5.98	0.645
25	1.15	1.15	-4.83	1.795
26	-0.19	-0.19	-5.02	1.605

Evaluating the performance by CUSUM chart

It is observed that if the scatter in the graph between energy consumption vs production of castings are random about the best fit line, then the differences from predicted energy use would also be random and not far from zero, and would track horizontally on the chart. It is however, if something happens which changes the pattern of energy consumption, the difference will not be random. They will be biased positive or negative and CUSUM will track up or down from the time of that event [Energy Management Handbook, 1999].

RESULTS AND DISCUSSION

- In Fig. 2 it is found that there are significant changes in the pattern even within short period of 26 days. The first change observed in day 3 reflecting event that increased energy efficiency during that day. The other changes in the pattern are observed for the following days 6, 10, 12, 16, 17, 19, 20, 21, 25 and 27. It is also observed that there is reduction in energy savings from day 22 onwards (poor housekeeping measures)
- From the fig. 3, it is observed that the proportion of energy that was not related to production varies from 17 to 20%. This variation is observed in accordance with the predicted equation along the month.

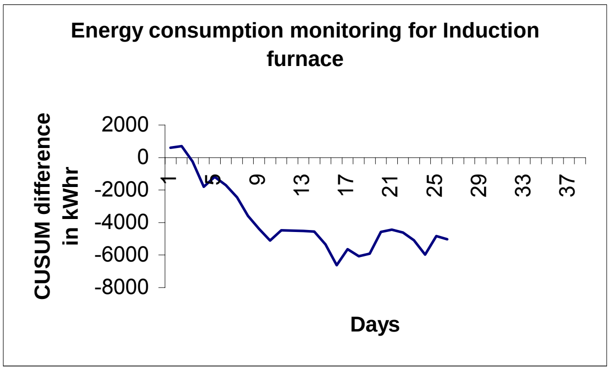

Fig. 2 Monitoring plotting from 1 to 26 th day

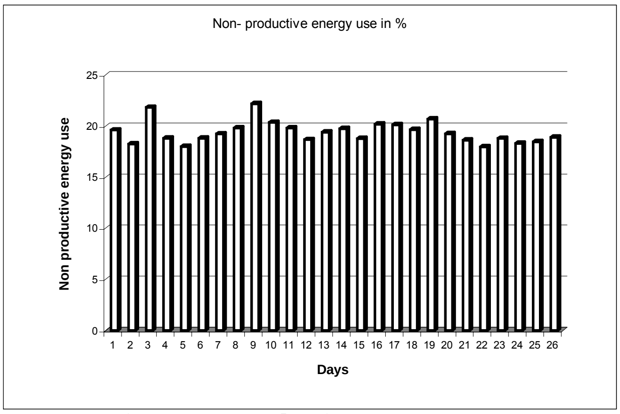

Fig. 3 Non productive energy use

- CUSUM chart calculates the effect of actions or events, which influenced on energy savings. From fig. 4 it is observed that the energy savings until day 26th is 5500 kWh.
- From fig. 5 of control chart, it clearly indicates that the energy consumption of melting process is well within the control since, no data crossed value of 'h' i.e. 3.75. The 'h' value acts as a decision control value.
- The fig. 6 shows the target setting based on energy saving results. It is observed that there is no change in new trend as both performance lines are near to each other and but R^2 value is slightly increase to 0.856 to 0.8677 in case of new performance line.

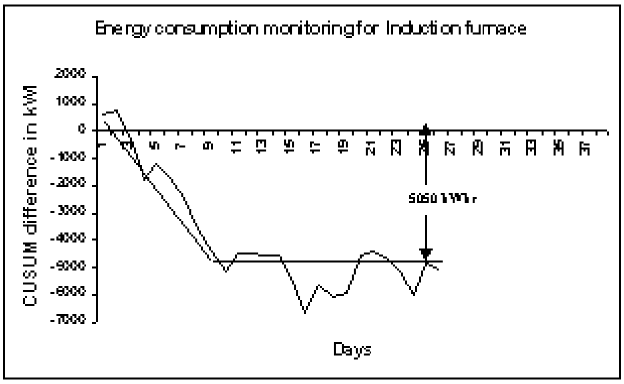

Fig. 4 Impact on the energy savings

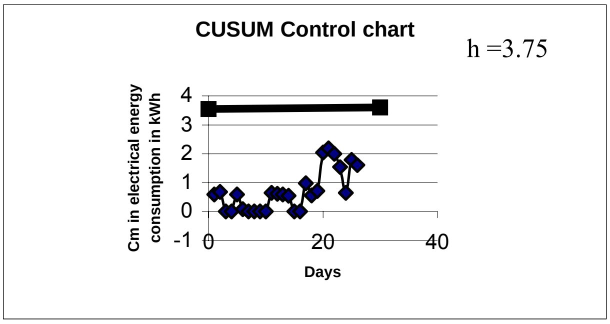

Fig. 5 process CUSUM control chart

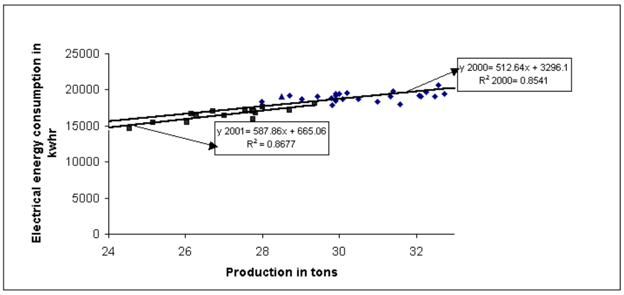

Fig. 6 New target performance line

CONCLUSION

Adoption of monitoring and targeting system will lead to increased and continued awareness of energy usage in industry. From this work it was found that, the excess energy consumption and energy savings were quickly highlighted through CUSUM plots. It was also observed that based on monitoring and targeting system, possible capital investment programmes or changes in working practices, can be aimed at obtaining further energy savings. Target setting is vital part of the energy management as it encourages in determining how low level energy consumption is achievable. It is also observed from this work that new target can be set based on energy savings achieved as mentioned in this paper. Further, this model can be used to develop a computer based monitoring system, which will take care of calculation of energy consumption, cost and CUSUM plotting for continuous monitoring information for different departmental reports.

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