METHODOLOGICAL ISSUES AND RESULTS OBTAINED FROM AN ENERGY AUDITING OF A FOUNDRY

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Abstract: The paper has a structure of four parts. In the first part is justified the concern of the authors regarding the electric energy audit (EEA). In the second part are specified the entities and the work style in elaboration of EEA for an energetic consumer that produces pieces made of aluminium alloy. The third part contains the synthesis of the results, as in the last part are given the conclusions obtained from analyzes.

Key words: electrical energy audit, energy efficiency, electro-thermal processes, optimization.

1. INTRODUCTION

Targets and means of action of the European Union are clearly defined and regulated [1, 2], aimed, in essence, by 2020, reducing energy consumption of fossil fuels by 20% and corresponding, increase in the share of renewable energy.

In Romania, energy efficiency is well below that of technologically countries. There are still many processes and services that take place in Romania, at an energy efficiency of [2-3] times higher than similar processes in technologically modernized countries [3÷7]. In the last period legislative and financial efforts [8, 9] are made to align Romania to the European Union standards, both in terms of energy efficiency and in terms of more intense use of renewable resources.

Audit of power (AP) is one of the ways covered [10], to identify ways of improve efficiency of processes of energy conversion. AP was conducted to an entity that produce pieces of aluminium alloy by melting, injection and hot / cold processing. After specifying the elements that define the contour and some specific aspects of mathematical modelling, there is given the conclusions of the made study with general interest, taking into account, the weight of the electro-thermal processes of Romania and the possibilities to increase the efficiency.

2. CONTOURS AND WAY TO WORK

S.C. Turnătorie Iberica (TI-C) is the industrial consumer choice, to exemplify the results by applying the AP. The contour is set to perform the AP at the factory level, with separate assessments on components of the general contour (Table 1.)

Table 1. Contour components to elaborate the AP

Nr. crt.	The name of the contour component (subcontour)
1.	Transformer and LV distribution network
2.	Compressors Station
3.	Pump Station
4.	Electro-thermal processes
5.	Mechanical processes
6.	Internal cranes
7.	Fans, exhausters
8.	Lighting installations

The technological manufacturing flow scheme is typical for a foundry of aluminium alloy pieces, by injection and finishing (Figure 1). Compressed air is used for driving the injection machines and the machines used for mechanic processing, and the industrial water circuit is used for cooling of the injection moulding machines. Methane gas is used as fuel for gas ovens (CP1÷CP4).

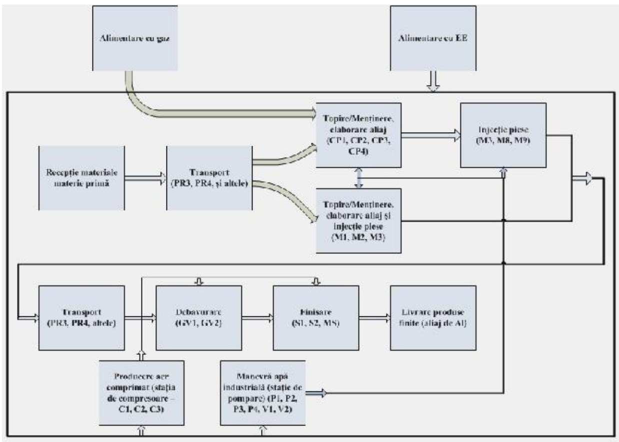

Fig. 1. The technology flow diagram of the TI-C

From the records made available by the beneficiary of AEE, August, September and October 2009 shows an average production of 55,994.46 kg pieces per month, made of aluminium alloy. Given this scheme of work at TI-C, [120 h continuous work (Monday - Saturday ÷ 06.00 A.M - 06.00 A.M.)], based on the records over those three months, we obtain the average value of hour production (productivity): 107.68 kg pieces per hour.

Fluctuations in demand from customers, require the use of the injection machines partially (M1 ÷ M9). Reference unit is one hour associated to AEE (hour AEE).

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The loading of the equipment during measurements were normal (medium), we specify that the equipment (M9, CP1, CP3, CP4) have not worked this time.
Please note that, ovens (CP1 ÷ CP4) works with methane gas (basic energy agent), EE is used only as a secondary agent (for ventilation and hydraulic).

Measuring instruments used:

• Network analyzer(AR) type C.A. 8334 B (2 pcs.), located in the secondary of the two transformers from each station;
• Protek 307 Clamp Meter Type
• Active and reactive energy meters:-TYPE ENERLUX TCDM-AEM Timişoara, located in the primary of the transformers.

For example, in table 2 and figure 2, we present some data referring to the energy consumption and production at the general contour level.

Table 2. Data referring to the production and energy consumption in the contour

Month	m^3 – gas	MWh	MVAr	kg Al processed
August	24450	130,52	35,92	28836,11
September	24492	216,28	60,97	56786,79
October	48431	236,32	70,28	81360,47

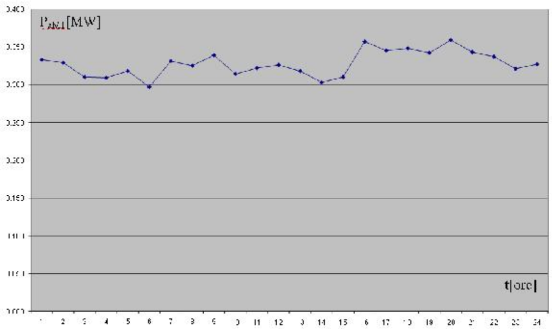


Fig. 2. Example given daily load curve at the general contour level (20.11.2009)

The network analyzer is used to highlight details of energy consumption (on each component) and power quality.
For example measurements are presented with reference to compressor station subcontur (three compressors) load curves that characterize the quality of EE elements:

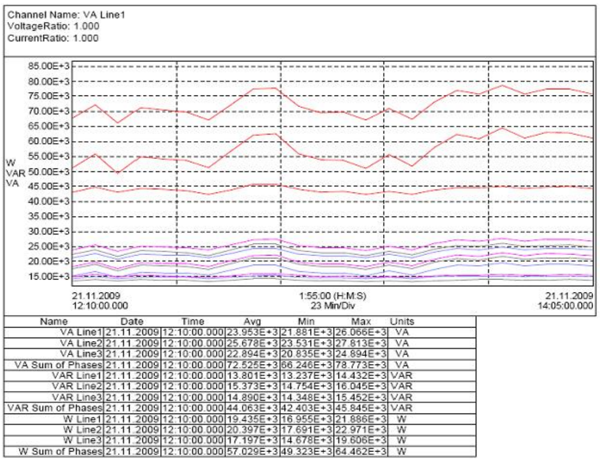
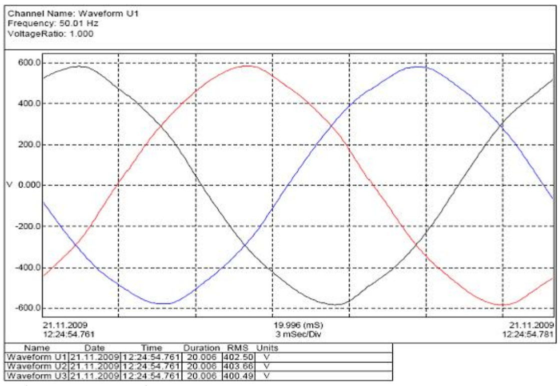
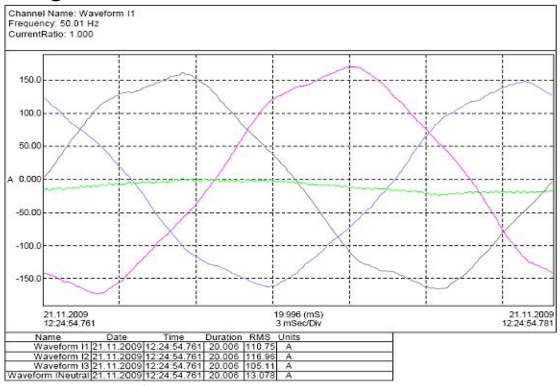


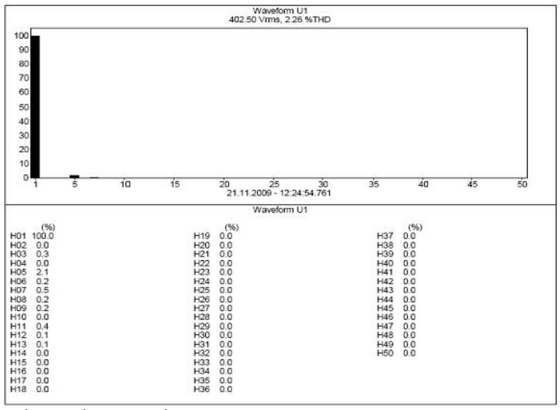
Fig. 3. Power load curve for compressor 1



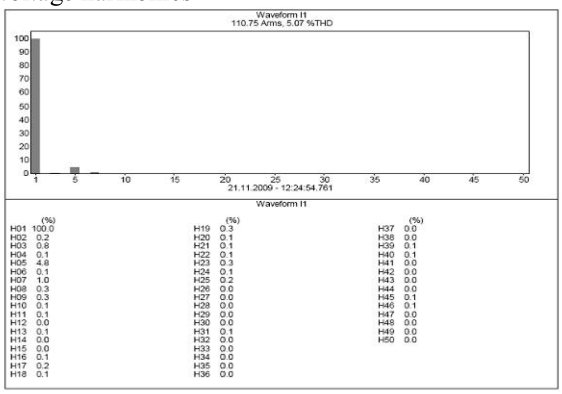
a) voltage waveform



b) current waveform



c) voltage harmonics



d) current harmonics

Fig. 4. EE power quality at compressor 1

The way to work at EEA is well known [9÷13].
BEE equations are specific to each sub-contour and for each type of equipment. For example BEE model is presented for the typical consumer case analysis.
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We present the mathematical models for AEE components of the subconturs :

- transformer station and distribution network:

$$W_{aMT} = W_U+\Delta W_T+\Delta W_L \quad (1)$$

- compressor station:

$$W_a = W_U+\Delta W_W+\Delta W_{FM}+\Delta W_L \quad (2)$$

- pumps station:

$$W_a = W_U+\Delta W_W+\Delta W_{FM}+\Delta W_L+W_{PV} \quad (3)$$

- electro-thermal processes:

$$W_a = W_U+\Delta W_{TR}+\Delta W_M+\Delta W_{mec}+\Delta W_L \quad (4)$$

- mechanical processes(the same for internal cranes, fans, exhausters, lighting installations):

$$W_a = W_U+\Delta W_M+\Delta W_{mec}+\Delta W_L \quad (5)$$

where:
W_{aMT} - energy absorbed
ΔW_T - loss of energy on power transformer
ΔW_L - loss of energy on short lines
W_a - absorbed energy determined by measurements
W_U - useful energy
ΔW_W - energy losses in motor windings,
ΔW_{FM} - energy losses in iron and mechanical
W_{PV} - energy absorbed in the ventilation and water cooling
W_{TRU} - useful heat, Al alloy maintained at a temperature of injection;
W_{MU} - useful mechanical energy
ΔW_{TR} - heat losses
ΔW_M - electric motor power losses
ΔW_{mec} - mechanical energy loss
Details are presented in [14].

3. RESULTS OBTAINED

Based on the equipment nominal characteristics and on measurements, using the mathematical models the EEA components were determined [14].
The results obtained are displayed in tables and Sankey diagrams - referring to the components and the general contour shape [14]. We give below some examples (Tables 3 ÷ 7 and Fig. 5 ÷ 8) for subcontur and results on real EEA over the general contour (Fig. 9 and Table 8)

Table 3. Real BEE results for compressors station

Feature size	[kWh]	[%]
A. absorbed energy [W_a]	160,1	100
B. output energy [W_i]	169,25	105,71
1. useful energy [W_U]	92,51	57,78
2. losses [ΔW]	76,81	47,97
• in motor windings [ΔW_W]	14,69	9,17
• in iron and mechanical [ΔW_{FM}]	61,49	38,41
• on short lines [ΔW_L]	0,63	0,39
C. closing error	-9,15	5,71

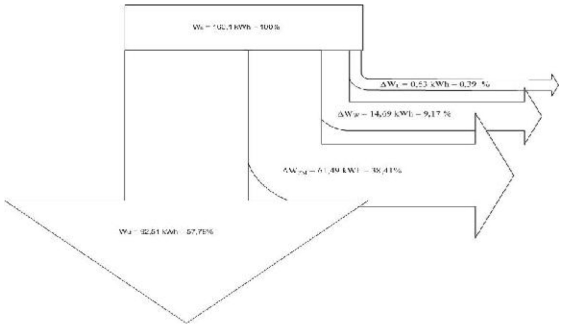

Fig. 5. BEE real Sankey diagram for compressors station

Table 4. Real BEE results for pumps station

Feature size	[kWh]	[%]
A. absorbed energy [W_a]	63,13	100
B. output energy [W_i]	65,19	103,29
1. useful energy [W_U]	28,25	44,76
2. losses [ΔW]	21,44	33,97
• in motor windings [ΔW_W]	4,25	6,73
• in iron and mechanical [ΔW_{FM}]	17,11	27,10
• on short lines [ΔW_L]	0,091	0,14
3. absorbed energy for water cooling [W_{PU}]	15,49	24,55
C. closing error	-2,06	-3,29

Table 5. Real BEE results for injection machines

Feature size	[kWh]	[%]
A. absorbed energy [W_a]	209,409	100
B. output energy [W_i]	209,588	100,09
1. useful energy [W_U]	89,01	42,50
2. losses [ΔW]	120,578	57,58
• thermal [ΔW_{TR}]	18,19	8,68
• on engines [ΔW_M]	30,61	14,62
• mechanical, in mechanisms [ΔW_{mec}]	71,35	34,07
• on short lines [ΔW_L]	0,428	0,21
C. closing error	-0,179	-0,09

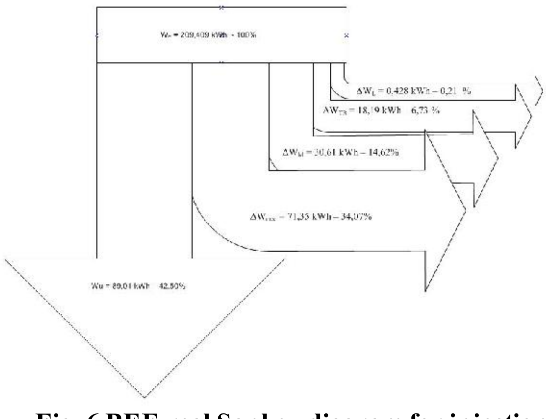

Fig. 6 BEE real Sankey diagram for injection machines

Table 6. Real BEE results for mechanical processing

Feature size	[kWh]	[%]
A. absorbed energy [W_a]	80,9656	100
B. output energy [W_i]	80,9656	100
1. useful energy [W_U]	9,238	11,41
2. losses [ΔW]	13,1076	16,19
• on electric engines [ΔW_M]	7,306	9,02
• on actuators [ΔW_{mec}]	5,755	7,11
• on short lines [ΔW_L]	0,0466	0,06
3. absorbed energy for air drying [W_{PU}]	58,62	72,40

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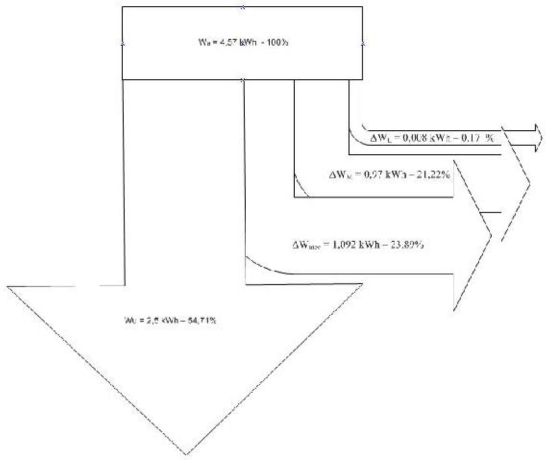

Fig. 7. BEE real Sankey diagram for internal cranes

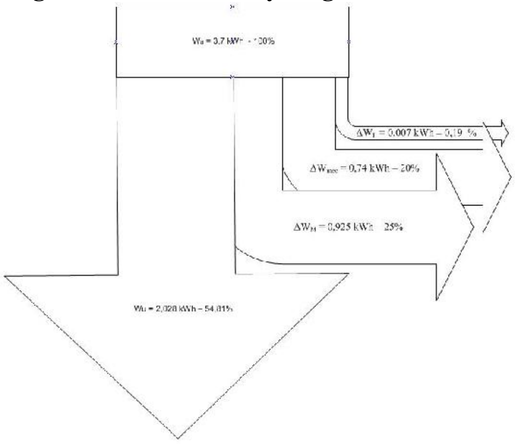

Fig. 8. BEE real Sankey diagram for fans and exhausters

Table 7. Real BEE results for lightning installation

Feature size	[kWh]	[%]
A. absorbed energy [W_a]	26,26	100
B. output energy [W_i]	26,26	100
1. useful energy [W_U]	14,492	55,19
2. losses [ΔW]	11,768	44,81
• on short lines [ΔW_L]	1,268	4,83
• in lightning installation [ΔW_I]	10,50	39,98

Table 8. Real BEE results for TI-C

Feature size	[kWh]	[%]
A. absorbed energy [W_{aMI}]	396,87	100
B. output energy [W_i]	405,33	102.13
1. useful energy [W_U]	153,21	38,60
2. losses [ΔW]	204,16	51,44
• on transformers [ΔW_T]	4,47	1,13
• on lines [ΔW_L]	42,3	10,66
• in motor windings [ΔW_W]	12,25	3,08
• on electric engines [ΔW_M]	24,66	6,21
• in iron and mechanical [ΔW_{FM}]	50,85	12,81
• mechanical, in mechanisms [ΔW_{mec}]	51,07	12,87
• thermal[ΔW_{TR}]	11,77	2,97
• in lightning installation [ΔW_I]	6,79	1,71
3. Auxiliary consumption	47,96	12,08
• for compressed air drying[W_{PU}]	37,93	9,56
• for water cooling [W_{PV}]	10,03	2,53
C. closing error	-8,46	-2.13

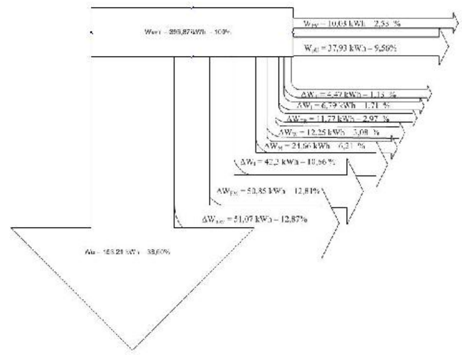

Fig. 9. BEE real Sankey diagram for TI-C

Indicators of efficiency that are suitable for characterizing the investigated processes :

a) EE specific consumption for unit of finished product:

$$C_W = \frac{W_{aMT}}{V_{PR}} = \frac{194{,}37 MWh}{55994{,}46 kg} = 3{,}47 kWh/kg \qquad (6)$$

b) Specific consumption of natural gas for unit of finished product

$$C_G = \frac{W_G}{V_{PR}} = \frac{38{,}791 mc}{55994{,}46 kg} = 0{,}69 mc/kg \qquad (7)$$

c) The amount of energy (EE and gas) for unit of finished product

$$V_{en/z} = \frac{C_{en}}{V_{PR}} = \frac{194{,}37\,\mathrm{MWh} \cdot 326\,\mathrm{lei/MWh}}{55994{,}46\,\mathrm{kg}} + \frac{38791\,\mathrm{mc} \cdot 1{,}064\,\mathrm{lei/mc}}{55994{,}46\,\mathrm{kg}} = 1{,}8687249\,\mathrm{lei/kg} \qquad (8)$$

4. CONCLUSIONS

Measurements and assessments of the power audit (EEA) of TI-C contour will draw the following conclusions:

4.1. Compressor station is sized for covering current air consumption. Compressors are suitable in technologically terms and have a good yield (57.78%). Voltage quality of the compressor station is in accordance with the regulations. Waves of voltage and current regarding the receivers on the structure of compressor station satisfy regulatory requirements relating to form, indicators (THD_U and THD_I) being in the acceptable limits. There is an unbalance currents for all receivers in the compressor station, which exceeds allowable limits for compressor C3 (79.4 A, 109.7 A, 57.4 A, 46.1 A);
This level of imbalance reflects internal defects of the receiver (most likely, electrical circuit defects), that involves damage to the functionality and power efficiency of the receiver. Power factor at compressor terminals is between 0.75 and 0.8.

4.2. Pump station is sized 2x100% compared with the current technological level imposed by the production, which is normal for the available for production but also for the security of water cooled components. Fans are operating close to rated power. Main pumps (P1, P2) have a good yield (63.4%) and auxiliary pumps (P3, P4) have relatively low efficiency (47%), mainly due to substantial losses in the iron and mechanical (4,52 kW) . Overall energy efficiency of the pumping stations, given the fans own technological consumption is 44.76% a value comparable to similar stations. Voltage in the connection point of the receivers in the pump station has adequate quality. However absorbed pump currents are outside the normal quality regulations, thus:

• pump P2: THD_I = 99.02%;

• pump P3: THD_I = 107.25%;

and current unbalance is very strong (3.7 A, 3.3 A, 5.4 A, 12.4 A) Quality of the currents absorbed by fans is normal. Power factor at the terminals of electrical receivers pumping station structure is in accordance with the load [0.71 - Main pump, 0.8 - other receivers]. Deviation from normal quality electricity to the pumping station is more blurry compared to the pumps deviation registered at: THD_I = 6.86% and the current system is effective values (117.8 A, 123.8 A, 117, 8 A, 12.8 A). This leads to the conclusion, found that there is a movement of pollutant residuum (distorted, unbalanced) between the two pumps, most likely because of pump P3 which may have a defect that leads to saturation (deformation current) and unbalance currents. It requires verification and remediation of pump P3 motor, and if case P2 pump motor.

4.3. Electro-thermal processes, dedicated essentially to maintain molten metal and inject it, represents the first category of processes in terms of hourly consumption (209.41 kWh to 160.1 kWh - Compressor Station).

We identified, in this category of processes, of a substantial reserve of working machines. Thus during the making of EEA only five injection machines and an oven operate, the other being stopped or defects.

Referring to the five injection machines for which were made specific EEA measurements and assessments:

• A greater dispersion of energy efficiency;

• A large dispersion of power losses such as heat;

• Very high mechanical loss mechanisms related to some injection machines.

These findings reflect the existence of large reserves of energy efficiency on the injection moulding machines.

The overall energy efficiency of injection moulding machines is 42.5%, below similar processes of the same type of machine and well below that of similar processes in witch are involved induction furnaces.

In terms of power quality, records reflect poor quality of current absorbed by the oven Guinea no. 2 (CP2).

Details of the EEA transformation processes in the TI-C, has a dedicated work.

4.4. Closing error of real EEA and of processes in which useful energy is calculated from effectiveness, such as those mentioned above, is admissible, in the limits imposed by rules [10], as follows:

• Compressor station: -5.71%;

• Pumping station: -2.06%

• Electro-thermal processes: - 0.09%

4.5. Mechanical processes are much less significant than heat treatment processes in terms of consumption of EE (80.97 kWh to 209.4 kWh). The most significant machine working within this group, in terms of consumption of EE is the vibration group. 1. Energy efficiency machining processes is low (11.41%), typical of such processes due to substantial losses on electric motors and transmission mechanisms between the motor and working tool and especially because of excessive consumption of the dryers EE ..

By the records resulting the following findings on the quality of EE:

• Working voltage at the terminals machines have waveform and value in accordance with the rules;

• Currents are strongly deformed at the working machines:

S1 (THD_I = 77.88%)

S2 (THD_I = 52.78%)

• For the vibrating processes group current has a pronounced deformation (THD_I = 19.41%)

• Currents have a strong unbalancing character at S2 (2.4 A, 1.7 A, 6.1 A, 10 A) and at vibration processes group (22.8 A, 21.9 A, 36.9 A; 20.3 A),.

These results reflect the existence in these machines of single phase saturated motors (magnetic). There is an unbalance of the currents for dryers, which exceeds allowable limits for dryer U1 (9.3 kVA, 3.1 kVA, 7.3 kVA)

This imbalance reflects the level of internal defects of the receiver (most likely defective electrical circuit) involves damage to the functionality and power efficiency.

Power factor of the working machines used in machining processes is highly variable: 0.16 (GV2), 0.22 (MS), 0.32 (S1), 0.56 (S2) and 0.85 (GV2). This reflects a load of these machines well below nominal value, except the group of vibration no. 1, the main consumer of this class. Shaker (V1) is equipped with oversized dryer substantially affecting overall efficiency.

4.6. Internal cranes have a very small share in total consumption (about 1%). Records reflect a much greater load to PR3 than to PR4. Overall PR effectiveness is good (55%), at the performance level of the same utility. Although the voltage is sinusoidal and balanced PR3 absorbs a strongly distorted system of current (THD_I =107.25%) and unbalanced (3.7 A, 3.3 A, 5.4 A, 12.4 A). PR4 has a pronounced unbalanced currents system (20.7 A, 20.1 A, 21.8 A, 12.3 A), reflecting the use and / or poor condition of the engines, most likely due to faults in the windings. The power factor of two internal cranes is well below neutral (around 0.3), reflecting their use and usefulness significantly below rated capacity, and the utility of the reactive power compensation.

4.7. Exhauster has a very small share in global consumption of the entity (under 1%) has a corresponding efficiency (55%), does not generates distorted and unbalanced system. Exhauster power factor is well below neutral (0.45), reflecting its sizing and utility of power factor compensation at terminal.

4.8. Lighting installations are concentrated mainly in two halls (3 and 4). Estimated energy efficiency and losses was based on the characteristics of these types of lighting equipment from the catalogue, achieving a 55% efficiency.

Lightning equipments affect the quality of EE, which is reflected by:

• Current wave deformation (THD_I = 12.15% - hall 3 and THD_I = 10.25% hall 4);

• Imbalance currents [(36.6 A; 20.5 A; 17.5 A; 23.4 A) - Hall 3 (29 A, 21.1 A; 28.1 A; 12.2 A) - Hall 4]

Power factor lighting installations is under the neutral (0.87 – hall 3, and 0.68 - hall 4). Very low value reflects the structural damage lighting capacitors.

4.9. From the records in the **transformers station** is established that:

• transformer is much under rated:

→ 414 kVA (average power) compared to 1250 kVA - for the period in which the records were made

→ 191.3 kVA (average power) compared to 1250 kVA - for 2009

→ 450 kVA (maximum power), compared to 1250 kVA - the period in which records were made

• The outgoing loads of the bar system are strongly unbalanced, so:

B1 - 4%, B3 - 60% B4 - 36%

• Change in the load in the transformers station is 26%;

• Quality of EE in the PT is within the limits allowed by the normative: 4% - the neutral conductor currents, compared with average current phase;

THD_U = 2.56%; THD_I = 3.85%;

Referring to the outgoing bar system, EE quality deteriorates in relation to the outgoing of PT, as follows:

• For bar B1 (27.7 A, 37 A, 32.3 A, 19.2 A) THD_U = 3.06%; THD_I = 5.91%;

• For bar B3: (400 A, 395 A, 390 A; 15.5 A) THD_U = 2.51%; THD_I = 3.67%;

• For bar B4 (247.5 A, 231 A, 235 A, 20.5 A) THD_U = 2.59%; THD_I = 5.28%;

EE quality level at PT outgoings through the three bars are within normal limits, except the B1 current system imbalance.

• Power factor of the LV bar of the PT is 0.95> 0.92 (Neutral), which reflects the existence and proper functioning of reactive power compensator at the PT station level.

4.10. For all contour, energy efficiency is 38.6% below the characteristic of similar processes and optimized performance. Power losses occur mainly in:

motors and mechanisms (35%) and electric distribution lines (11.7%). A significant proportion (12.08%) in the auxiliary consumption aids mainly because of the air dryers (9.56%)

4.11. Based on records from three months of 2009, efficiency indicators were calculated [14]. There are reserves to improve these indicators.

4.12. Reduce electricity consumption can be made by applying the following measures:

A reduction of dryers from the mechanical processing;

B. Deep maintenance of some working machines;

C. The gradual replacement of mercury vapor lamps, with sodium vapor lamps

By applying the measures described above, in accordance with the specifications of [14] the reducing of energy losses and technology auxiliary consumption is obtained, leading to the reduce of the energy absorbed. The optimal EEA of TI-C is shown in Figure 9 and Table 10:

Table 9. Optimum BEE (for one hour) components for TI-C

Feature size	[kWh]	[%]
A. absorbed energy [W_{aMI}]	331,44	100
B. output energy [W_i]	338,15	102.02
1. useful energy [W_U]	153,21	46,23
2. losses [ΔW]	154,38	46,58
• on transformers [ΔW_T]	4,23	1,28
• on lines [ΔW_L]	36,01	10,86
• in motor windings [ΔW_W]	9,15	2,76
• on electric engines [ΔW_M]	23,9	7,21
• energy losses in iron and mechanical [ΔW_{FM}]	48,95	14,77
• mechanical, in mechanisms [ΔW_{mec}]	20,28	6,12
• thermal [ΔW_{TR}]	7,58	2,29
• in lightning installation [ΔW_I]	4,28	1,29
3. Auxiliary consumption	33,88	10,22
• for air drying [W_{PU}]	23,85	7,19
• for water cooling [W_{PV}]	10,03	3,03
C. closing error	-7,06	-2.13

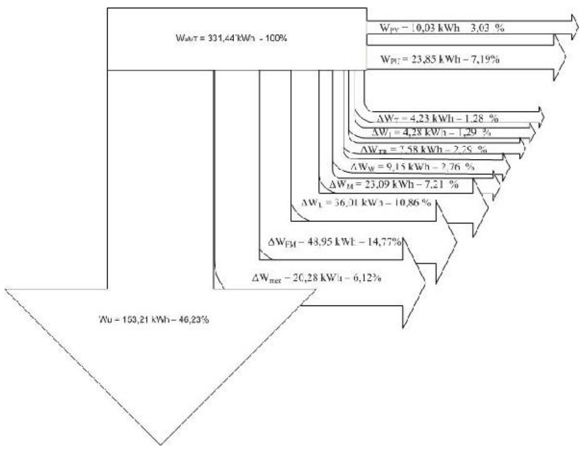

Fig. 10. BEE (one hour) optimum Sankey diagram for TI-C

By reducing EE consumption the efficiency indicators improve, as follows:

• EE specific consumption per unit of finished product will be:

C_w = 2.897918 kWh / kg

• Energy cost per unit of finished product will be:

$V_{en\,/\,z}$ = 1.682159389 RON / kg

Reduce consumption of EE leads to reducing the environmental impact. Reducing the estimated quantities of pollutants discharged into the atmosphere for the reference unit (one hour) are presented in Table 10.

Table 10. Reducing the quantities of pollutants by optimizing

Pollutants	Reduced quantity[kg]
SO_2	2,5669
NOx	0,04739
CO_2	23,197

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