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Study of the electricity consumption reduction of a compressed air system: the case of a steelmaking company

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Abstract

This work aims to reduce the energy consumption and thus increase the availability of blast furnace compressors of a steelmaking company, located in Alto Paraopeba region in Minas Gerais state, Brazil, through the elimination of waste points in the compressed air distribution. In order to develop this work, an ultrasound test in the compressed air line was performed to identify and quantify leaks in the flow. Once the leaks were identified, they were eliminated through corrective maintenance and improvements, and then the energy consumption scenarios before and after the improvements were compared. As a result, the average monthly electricity consumption in the reporting period decreased by 57.2%. In addition, one compressor was set aside in stand-by condition, as in the original plant. Thus, one can prove the efficiency in eliminating of waste points in compressed air distribution, since the reduction of energy consumption is important for the company to remain competitive, as the cost of electric energy affects the final price of the final products.

keywords: compressed air, compressor, energy efficiency, ultrasound test, leaks.

1. Introduction

Humankind has been using compressed air since its existence for the simple act of blowing a brazier to light a flame. Lungs may be considered compressors, since they are able to process 100 L/min or 6 m³/h of air, using a pressure from 0.02 to 0.08 bar (Atlas Copco, 1976). Through this simple example, the importance of the compressed air use to humanity is demonstrated.

Currently, compressed air deliveries power to a wide variety of industrial operations, comprising of small plants to heavy industry, being used in virtually all stages of production.

A generic pneumatic system can be divided into three parts: generation, distribution and end use. Rocha and Monteiro (2005) characterized each one as: (i) generation unit includes the compressor driven by an electrical motor (which captures the gas and increases its pressure), automation and control, air handling equipment, tank and accessories; (ii) distribution unit takes the compressed air from the reservoirs to the end use, ensuring that this air reaches the optimal quantity and pressure free of water and impurities; (iii) at the end use unit, the application is varied, for example, to drive pneumatic tools and camshafts.

Electrical energy is consumed for the generation of compressed air. According to Rocha and Monteiro (2005), compressed air is one of the most expensive energy forms in an industrial plant, with the largest expenditures in electricity consumption, which may represent 30% or more of the total electricity consumed.

Thus, with the increasing market competitiveness, companies have continually sought to reduce operating costs to keep their products at competitive prices, ensuring the satisfaction of their customers and shareholders. It is important, therefore, to make conscious compressed air consumption in order to avoid unnecessary costs.

According to Beyene *apud* Raduenz *et al*. (2009), the main cause of waste in pneumatic systems is leaks. Rocha and Monteiro (2005) state that these leaks can represent in industrial compressed air systems without maintenance, 10 to 40% of the maximum compressed air demand, being the admitted value for losses of up to 10% for steelmaking industries (Macintyre, 1996).

In order to avoid the compressed air depletion through leaks, the maintenance of all compressed air distribution is necessary. According to Xenos (2004), maintenance activities prevent degradation of equipment and facilities caused by their use, wear and tear. This fact generates losses of performance and production downtime, besides of the manufacture of poor quality products and environmental pollution.

One of the biggest uses of compressed air in industry is the manufacture of iron and steel. It takes approximately 3,000 cubic meters of compressed air to produce 1 ton of steel. Rollins (2004) highlights some applications for compressed air: "Compressed air is used in the iron and steel industry for many purposes in addition to the basic process, mainly as a drive force from the functional equipment and tool. These applications include deburring and grinding ingots, trigger hoists and lifts, shake solutions, blast and caulk tanks. They also include the operation of machines to punch, carvings, oven doors, instrumentation and process control, dumper ingots, drive bell of a blast furnace and coke gates, lubrication systems, clutches and pneumatic brakes, mixing materials, descaling, pneumatic clamps, etc.

In this context, the compressed air system of a steelmaking company is studied. The steelmaking plant has 169 air, argon and nitrogen compressors. The compressors are from Ingersoll Rand, Atlas Copco, Chicago, Sullair, and Worthington and Wayne, all driven by electric motors, with power ranging from 5 to 500 kW. Because of the plant size, several compressed air centrals are located in each production area, among them the blast furnace one.

According to the company (2013), the blast furnace production area is responsible for delivering molten metal, having an installed production capacity of 1.5 million of tons per year. It has three compressors from Atlas Copco; model GA315W with rated power of 271 kW. Each compressor at full load is able to deliver about 2790 m³/h of compressed air with an average pressure of 7.4 bar (7400 kPa) for the production process.

The target area of the study has three compressors; one should work full time, the other one as charge and relief, and the last one as stand-by, only triggered in the event of temporary need. This was the initial plan for the area. However, in practice, one compressor works full time and the other two compressors works in charge and relief to meet the demand. Taking the question of availability into account, in case of stopping one of the machines for maintenance, the compressed air delivery is compromised. In parallel, the overloaded operation of the system raises the costs of electricity, raising the production costs of the company. Thus, the study aims to reduce the final energy consumption of the blast furnace plant compressors and to return the compressor to optimal working condition, according to the initial design of the plant.

According to Gonçalves and Cardoso *apud* Junior and Peixoto (2010), energy is the biggest expense in compressed air systems, accounting for 73% of total expenditure, which confirms the importance of energy efficiency of these systems.

Rollins (2004) alleged that valves, records and joints lose a considerable amount of compressed air, which when added up may total a huge amount of losses. In addition to leaks in the distribution accessories, holes in the pipe must be considered. Atlas Copco (1976) and Rock and Miller (2005) stated that for a working pressure of 6 bar (600 kPa), the power required to supply the lost compression on a 1 mm hole is 0.3 kW, for 3 mm hole is 3.1 kW, and for 15 mm hole is 132 kW, which shows an exponential growth in electrical power.

To illustrate the losses in financial terms, a hole of 10 mm of diameter, slipping 6.3 m³/min of compressed air at 6 bar for 24 hours, in a year generates an approximate additional expenditure of R$ 49,100.00 (about US$ 19,640.00, considering 2.5 R$ = 1 US$). In this case, the average value of R$ 0.17 kilowatt-hour is considered and corresponds to the electricity tariff, off-peak, subgroup A2 (88-138 kV), charged by Minas Gerais Energy Company (CEMIG) in 2014, with no government taxes (ICMS, PIS / PASEP, COFINS and public lighting contribution).

However, it is likely that there are more holes of varying diameters in a compressed air distribution piping, which increases the additional expenditure in electricity. Thus, one can infer that the maintenance of pipes is highly rewarding, and can even prevent unnecessary replacement of a compressor with a higher capacity (Rollins, 2004). Thus, the study of the losses in the compressed air distribution system of the blast furnace plant is justified, since the compressors are not working according to the initial plan design, consuming electricity in excess.

2. Material and methods

For the study, some procedures that assisted in the collection and discussion of the data must be followed. The compressed air delivery line is subjected to a visual inspection and an ultrasonic non-destructive testing, to identify waste points. Non-conforming points were identified with tags, photographed and stored.

The first data collected related to the project is carried out in the field where the operation of the equipment is analyzed. Based on the perception of non-conventional operation of the compressor, the dispensing line is subjected to an ultrasound test so that waste points are measured. Ultrasonic measurement is performed by Ultraprobe® 10,000 device of UE Systems. This device is the latest technology, able to perform condition analysis, record sounds, and store and manage data. In addition, through a photography camera, a record of the necessary data is made.

From the supervisory system and data acquisition, which records and stores all the data on the electromechanical equipment of the blast furnace plant, the energy consumption of compressors is obtained at any time.

The data provided by the ultrasound device were treated by the software Compressed Gas Loss Guess-Timator, provided by the manufacturer. Once treated, these data were arranged in the Microsoft Excel spreadsheet software, as the data obtained through the monitoring system and data acquisition, allowing the tab and their critical analysis.

After identifying the waste points, it is necessary to eliminated them. Once this step is completed, the electricity consumption before and after the elimination is compared, in order to verify the gains in terms of energy consumption.

3. Discussion

The company was established in Brazil in the early part of the twentieth century. Over the years, the company grew and added more manufacturing plants in Brazil and abroad. With a wide range of products marketed to the five continents, the group operates in the sectors of construction, industry and agriculture. This work was performed using a specific plant in this company. This plant was established in 1986 and is one of the major steelmaking industries of Brazil. Its product mix consists of billets, slabs, blooms, rolled structural shapes of parallel tabs, wire rod, and carbochemical products.

In the production system, the blast furnace of Chinese origin is responsible for the molten metal delivery, having an installed production capacity of 1.5 million tons per year. For the plant operation, compressed air is necessary to meet the demand of pneumatic tools, pneumatic cylinders, among other applications. There is a unique compressed air system to meet the demand of this plant. Thus, the compressed air system is comprised of three compressors from Atlas Copco, GA315W model with power rating of 271 kW. Each compressor at full load is able to deliver about 2790 m³/h of compressed air with an average pressure of 0.74 MPa for the production process.

In the initial design project, one engine should work full time, the other in charge and relief, and the last one on standby, ie only triggered in the event of temporary need. However, in reality, one engine works full time and the two others in charge and relief to meet the demand,
increasing the power consumption of the compressed air system.

In order to quantify the wasted amounts of compressed air, an ultrasound test on the compressed air distribution line of the blast furnace was performed. In order to process the data and get reliable results, an outsourced company with extensive experience was used for tests of this nature.

The data provided by Ultraprobe® 10,000 unit of UE Systems are acoustic data in dB unit, and through the Compressed Gas Loss Guess-Timator software, provided by the manufacturer, these values are converted to m³/h, making it possible to measure the flow of wasted air. Table 1 shows the results.

Observing Table 1, all waste points were numbered and arranged in the first column. The second and third columns refer to the location of the identified leaks. In the fourth column, the designed pressure value in the line is 100 psig. Then, in column five are the acoustic measured values (in dB), and finally, in column six is shown the flow calculated by the Compressed Gas Loss Guess-Timator software (in m³/h). Through Table 1, one can identify thirty-seven points of leakage, which results in a rate of 475.01 m³/h, confirming the potential energy gain if these are eliminated.

The values shown in Table 1 are indicative as they are specifics and these leaks may vary over time. Through the power (271 kW) and flow (2790 m³/h) of the compressor, the calculated energy loss was approximately 33220 kWh/month.

Among the points collected, the
number 15 and 36, which have measuring 120 dB, are considered the higher values, which for example are equivalent to a turbine aircraft in operation. These points do not deal with leaks, but incorrect use of compressed air. In this case, the calculated flow rate can be greater than 22.19 m³/h as shown in Table 1, since the equipment has reached its upper limit measurement. The incorrect application of compressed air is checked because there is a hose blowing compressed air in the main loading belt of the blast furnace (C1 belt), acting as a cleaner; an activity that should be performed by a scraper. It is noteworthy that this is not a standard operating procedure error but an improper installation made for convenient operation. In this case, the measurement points were identified and performed despite the ultrasound test not being recommended because it is not a leak. The problem is recurrent in the secondary belt furnace loading (C2 belt). It is noted that the adoption of compressed air for cleaning the belts is provisional. The original scrapers broke and have not been replaced, and compressed air is being functional, but costly, since the compressed air supply is not interrupted.

Leaks in the other points collected are due to inefficient maintenance of pipe fittings, primarily cylinders, valves and filters. From Table 1, it is observed that point 6 shows the acoustic measured value of 81 dB which corresponds to a rate of 12.26 m³/h. In this case, the valve was no longer functional and the leak has not been recognized by means of a daily inspection, only in data collection for this work.

Table 1
Results of ultrasonic measurements and compressed air flow loss.

Point	Area	Position	Line pressure (psig)	Acoustic measurement (dB)	Calculated volumetric flowrate (m³/h)
1	Compressors room BF	Air dryer number 1	100	100	16.26
2	Dedusting of BF	Line filter	100	97	15.61
3	Dedusting of BF	Air Reservoir	100	62	8.57
4	Dedusting of BF	Valve of chamber 7 right side	100	87	13.49
5	Dedusting of BF	Final Valve in the right side	100	61	8.38
6	Dedusting of BF	Final Valve in the left side	100	81	12.26
7	Dedusting of BF	Valve of chamber 7 left side	100	75	11.06
8	Raceway area BF	Service valve	100	62	8.57
9	Raceway area BF	Operation room of cannons 1 and 2	100	81	12.26
10	Raceway area BF	Refrigeration panel of the punch drill 2	100	95	15.18
11	Raceway area BF	Panel of the spout 4	100	63	8.75
12	Raceway area BF	Panel of the spout 1	100	71	10.28
13	Raceway area BF	Punch service valve 1	100	62	8.57
14	Raceway area BF	Refrigeration panel of the punch drill 1	100	100	16.26
15	Topo do BF	Blower of the belt C1	100	120	22.19
16	Regenerator of BF	Service air near stairs	100	72	10.47
17	Pulverized coal injection of BF	Line lubricator jumper left	100	100	16.26
18	Pulverized coal injection of BF	Line lubricator 6th floor	100	77	11.45
19	Dedusting of BF	Pressure vessel of dedusting	100	83	12.67
20	Dedusting of BF	Pressure vessel of dedusting	100	64	8.94
21	Dedusting of BF	Cylinder 1 of right side	100	84	12.87
22	Dedusting of BF	Gauge of the camera 1 on the right	100	95	15.18
23	Dedusting of BF	Cylinder 1 of left side	100	94	14.97
24	Dedusting of BF	Cylinder 2 of right side	100	81	12.26
25	Dedusting of BF	Cylinder 2 of left side	100	64	8.94
26	Dedusting of BF	Cylinder 3 of left side	100	84	12.87
27	Dedusting of BF	Cylinder 4 of right side	100	81	12.26
28	Dedusting of BF	Cylinder 4 of left side	100	76	11.26
29	Dedusting of BF	Cylinder 5 of left side	100	91	14.33
30	Dedusting of BF	Cylinder 6 of right side	100	73	10.66
31	Dedusting of BF	Cylinder 6 of right side	100	81	12.26
32	Dedusting of BF	Cylinder 7 of right side	100	101	16.48
33	Dedusting of BF	Cylinder 8 of right side	100	101	16.48
34	Dedusting of BF	Cylinder 6 of left side	100	89	13.91
35	Loading BF	Activation of the TC C2	100	79	11.86
36	Loading BF	Blower of the belt TC C2	100	120	22.19
37	Dedusting of BF	Line Filter	100	63	8.75
		TOTAL OF LEAKS			475.01

Another common source of leaks are line filters. Line filters have a useful life determined by the manufacturer and must be strictly replaced. If this procedure is not done, it can decrease the flow rate and/or air pressure, and may even stop the line. Therefore, by the data presented in this section, the large number of losses in the compressed air distribution is confirmed. The elimination of these points can save 475.01 m³/h of compressed air, which may have

greater savings considering the observations related to the points 15 and 36.

In order to solve the problems related to compressed air distribution waste in the blast furnace plant, an action plan was proposed. It is suggested that leakage points should be minimized and changes made related to the cleaning of loading belts.

First of all, the elimination of leakage points consists of corrective actions. However, the loading belts of the blast furnace cannot be without cleaning, so

compressed air was not eliminated immediately. Although this is costly and not ideal, the compressed air performs the function of keeping the belt clean. Thus, a permanent solution is needed before the elimination of the compressed air hoses.

In the blast furnace project, scrapers for cleaning the belts were projected. This equipment is indicated by companies that work in the area of the belt conveyor. So, scrapers have been specified for elimination of the use of compressed air. The C1 belt scraper project, related

to the point 15 is shown in Figure 1a. It is a polyurethane blade able to clean effectively in extreme environments. The cleaning of the belts is important to prevent material accumulation that can adhere to rollers and other accessories, shortening the life of the assembly and keeping the environment clean. The scraper installed is displayed in Figure 1b.

It is noted in Figure 1b that the compressed air hose has been eliminated and the scraper performs the cleaning function correctly.
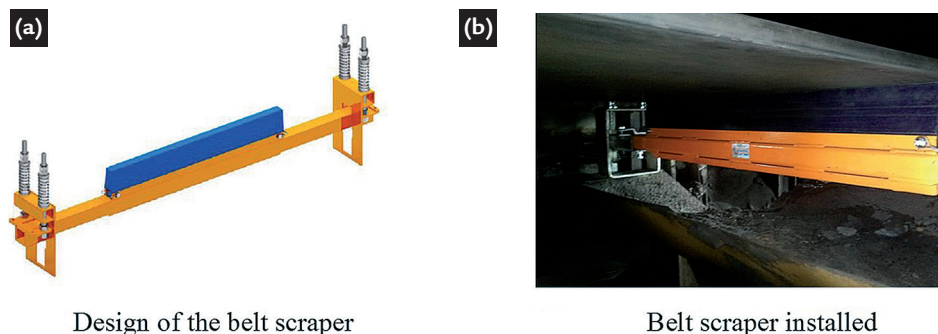
Figure 1
Belt Scraper of the C1 area:
(a) design and (b) installed

(a) Design of the belt scraper

(b) Belt scraper installed

Despite the improvements made, it is necessary that they remain so leaks are non-recurring. Therefore, the future implementation of an inspection plan in the compressed air distribution of the blast furnace plant is required. It was found that the identified problems are arising from the absence of more detailed standard operating procedures and directed activities and responsibilities.

After the implementations, the electricity consumption of the compressors was monitored. Through the supervision system and data acquisition available in the blast furnace plant, the energy consumption of compressors was obtained over a defined period.

Table 2 shows the electricity consumption of the three compressors from September 2012 to September 2013 as

well as the total cost spent in electricity of the air compressed system. These data refer to the period prior to the elimination of waste points in compressed air system. Table 2 shows that the average electricity consumption of the compressors between September 2012 and September 2013 was 32,785.42 kWh, which corresponds to an average monthly cost of R$ 52,259.38.

Table 2
Monitoring the energy consumption of blast furnace compressors before elimination of waste points.

Month	Global electricity consumption of compressors (kWh)	Average cost of kilowatt-hour for the power plant	Total cost spend in electricity
Sep/2012	345574.04	R$ 0.17	R$ 58,747.59
Oct/2012	347501.71	R$ 0.17	R$ 59,075.29
Nov/2012	343234.70	R$ 0.20	R$ 68,646.94
Dec/2012	358553.03	R$ 0.18	R$ 64,539.55
Jan/2013	362625.60	R$ 0.17	R$ 61,646.35
Feb/2013	321021.12	R$ 0.15	R$ 48,153.17
Mar/2013	338006.64	R$ 0.18	R$ 60,841.20
Apr/2013	275169.60	R$ 0.15	R$ 41,275.44
May/2013	306282.48	R$ 0.16	R$ 49,005.20
Jun/2013	319464.00	R$ 0.13	R$ 41,530.32
Jul/2013	319570.32	R$ 0.13	R$ 41,544.14
Aug/2013	309504.00	R$ 0.13	R$ 40,235.52
Sep/2013	315223.20	R$ 0.14	R$ 44,131.25
Average	327825.42	-	R$ 52,259.38

After performing the improvements, the compressors electricity consumption and the total electricity cost spent in the air compressed system was monitored and reported in Table 3.

Month	Global electricity consumption of compressors (kWh)	Average cost of kilowatt-hour for the power plant	Total cost spend in electricity
October 2013	129,701.52	R$ 0.12	R$ 15,564.18
November 2013	134,388.00	R$ 0.13	R$ 17,470.44
December 2013	180,561.36	R$ 0.12	R$ 21,667.36
January 2014	136,695.12	R$ 0.13	R$ 17,770.37
February 2014	120,274.56	R$ 0.14	R$ 16,838.44
Average	140,324.10	-	R$ 17,862.16

Table 3
Monitoring of electricity consumption of blast furnace compressors after the elimination of air compressed system waste points.

Table 3 shows that from October 2013, the drop in electricity consumption was drastic due to the elimination of the air compressed system's leakage points.

Note that the average consumption of the three compressors fell from 327,825.42 to 140,324.11 kWh per month, which means a reduction of 57.2% in energy consumption. Consequently, it was possible to return a compressor to stand-by condition, according to the plant's initial design, without changing the delivery pressure of the compressed air.

According to the ultrasonic measurement prediction, the waste of compressed air system required an electrical energy consumption of 33,220 kWh/month. However, after improvements, the reduction was far greater, showing an average value of 187,501.31 kWh. The difference between the calculated value and the actual reduction in consumption is due to the fact that the tests only detect leaks, and the flowrate calculated in cleaning the C1 and C2 belts were below the real value and thus do not provide the correct compressed air leakage. The drop in electricity consumption is also displayed in Figure 2. In this figure, it is evident that the decrease in electricity consumption occurs in the month of October 2013.
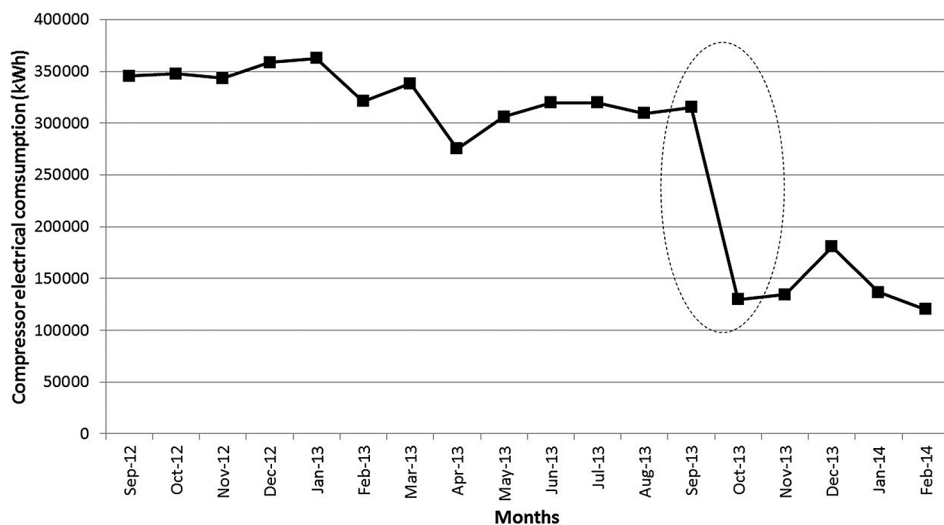

Figure 2
Electricity consumption of blast furnace compressors.

Figure 2 displays that the electricity consumption decreased about 185,000 kW between September 2013 and October 2013, which corresponds to 57.2% of electricity consumption reduction. The decrease in costs because of the elimination of waste points, mainly by the installation of scrapers in the belts, was around R$ 15,000.00. This study proves the feasibility of eliminating the compressed air system waste points.

4. Conclusions

Compressed air is typically one of the most expensive utilities in an industrial facility. Based on energy assessment of mid-sized industries, compressed air typically comprises from about 5% to 20% of a plant's annual electric costs (Schmidt and Kissock, 2015). In this paper, it was found that there was no effective standard operating procedure for inspection and maintenance of the compressed air system of a company, and through an ultrasonic test, it was found that leaks were responsible for the high electric energy consumption of the compressors. Thus, the elimination of these leaks was made in order to solve the problem, the elimination of compressed air waste points generated an average monthly reduction of about 185,000 kWh or 57.2% in electricity consumed by the compressors, which is equivalent to the consumption of a compressor Atlas Copco GA315W. Therefore, it was possible to return a machine to stand-by condition. However, to keep the optimal

functioning of the compressed air system and a non-recurring problem, it becomes necessary to create a more detailed standard operating procedure and directed activities and responsibilities. The work on the energy consumption reduction of the blast furnace of a steelmaking process compressors is of main importance for the understanding of how the bad use of compressed air has a negative impact on the consumption of electric energy. In this sense, additional studies were proposed to further reduce the energy consumption of compressors and, jointly, increase their availability.

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