Identifying damage in reciprocating air compressors

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Abstract

We used a parametric analysis for a reciprocating air compressor to determine its working conditions. We also connected measuring devises which allowed us to determine the real performance of our compressor. From this point we were able to simulate the most common damage or failures and analyze how these parameters vary according to those deviations created under its normal operation. We also created a computer program based on the compressor's real performance, which estimates its operating parameters with the minimum information available for the compressor's operator.

Sinopsis

Identificación de daños en compresores de aire de pistones

Usamos el análisis paramétrico para un compresor de aire de pistones para determinar sus condiciones de operación. También colocamos instrumentos de medición que nos permitieron determinar el desempeño real del compresor. Luego de esto fue posible simular los daños o fallas más comunes y analizar cómo estos parámetros variaban de acuerdo a las desviaciones creadas en las condiciones normales. Además desarrollamos un programa de computadoras que, a base de los parámetros reales del compresor, estima los parámetros de operación del compresor con la mínima información disponible para el operador del compresor.

Introduction

Some facts found in a professional magazine related to air compressors and the importance of their efficiency, reliability, serviceability, useful life and cost captured our attention:

1. In some areas of the United States, up to 30% of the electrical energy produced is used to compress air.
2. In some industrial sites, up to 70% of the plant's electrical demand is consumed by air compressor. In Puerto Rico 95% and even more of the manufacturing facilities count on compressed air systems.

Air is compressed by different types of compressors, either positive displacement or dynamic displacement. The most commonly used is the reciprocating air compressor (piston), which is part of the positive displacement type of compressor. This usage justifies the need to develop new and easy methods to maintain and assure the proper performance of these compressors. Therefore it is important to detect future failures via non destructive tests in air compressors, avoiding monetary losses in non productive time. Generally, the cost of operating an air.compressor for a whole year is from two to three times the purchase price of the compressor. Few people realize its importance in production, but the fact is that if there were no air compression, there would be no product or service.

It is not surprising, then, that many manufacturing companies would pay an engineer large amounts of money to ensure that their compressors would not go down at the most critical moment. Whereas this can be performed by a well trained technician with the right tools, a set of equations can tell him when something is wrong and will also help in the development of preventive maintenance programs. This research introduces a new method of diagnosing the internal conditions of a reciprocating air compressor.

With this nondestructive method of quantifiying the operating parameters we can evaluate the cylinder pressure, the operating temperatures, the heat transfer conditions, the leakages and power comsumption of a reciprocating air compressor. Then we can use instruments to measure those values and thereafter establish the operating parameters of the air compressor. Thus we developed a set of equations and a computer program that will tell the operator or compressor user without a wide knowledge in engineering, whether the compressor is working in the designed range of parameters. With these results it is possible to define the operating parameters as:

- Good, that means the compressor is operating within its optimal range and no action is required at this time
- PM, which stands for the need of preventive verification of the compressor or that a small deviation from the desired operating parameters has been noticed.
- Bad, which means stop

Experiment

To find the real operating parameters for our compressor, we performed the experiment to be described in the following paragraphs[1]. The recommended method for acceptance testing of displacement compressors is given by the international standard "ISO1217 Displacement Compressors Acceptance Test," as well by the national standards based on this ISO document.

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[1] "Acceptance testing of displacement compressor's", Atlas Copco Manual, chapter 9.

Figure 1 shows the required measuring points, among others: the barometric (atmospheric) pressure, the temperature, the humidity pressure, the temperature at the inlet flange, the intercooler pressure, the pressure and temperature before the orifice or nozzle, the pressure drop over the orifice or nozzle, the amount of condensate collected in the intercooler, aftercooler and air receiver, and the electric power input. When testing packaged and portable air compressors, the inlet point is taken to be the surrounding atmosphere and the outlet is the outlet valve. The international standard ISO 1217 also stipulates the intake reference conditions, which are the dry air of one bar (14.7 psi) absolute pressure for the intake and the temperature equal to that of the intake air for the coolant.

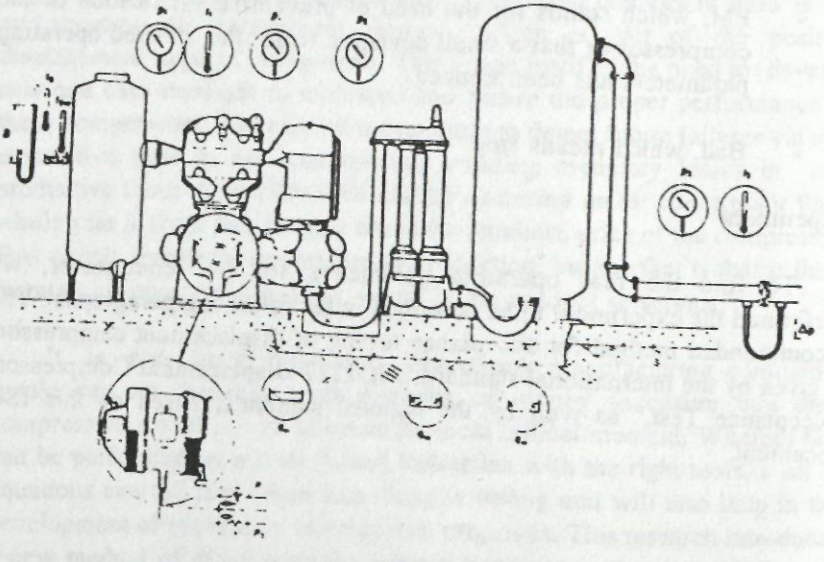


Figure 1. Measuring points for compressor acceptance testing

It is important to mention that, even though ISO standards recommend measuring many parameters, we considered only those directly related to the compressor itself for its performance analysis. This means we did not measure any parameters from elements such as the aftercooler, the dryer, the air receiver and the separators. Our major problem while trying to measure the operating parameters of our compressor was making sure not to change the compressor's performance by adding leaks or constraining its flow conditions when inserting measuring devices. For this reason we used specially designed fitting adaptors.

With these adaptors we were able to install a thermocouple and a pressure gauge at each of the test points shown on figure 2.

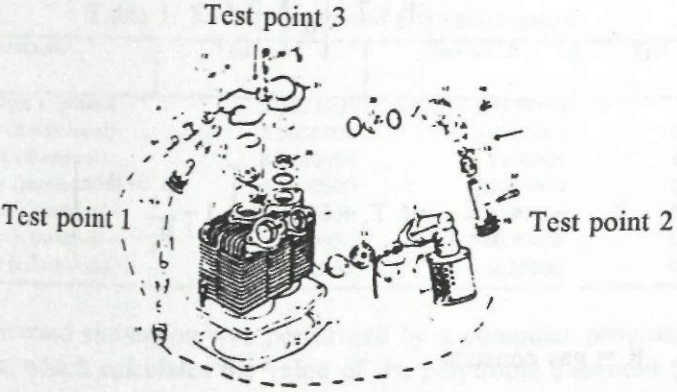


Figure 2. Test points of our air compressor

Computer and failures simulation

There was one question still open in our project: Will we really, by measuring and analyzing the compressor's operating parameters, be able to detect any damage caused to the compressor? To answer this question we performed two types of computer simulations.

It is very important to mention that some of the parameters used were determined with the manufacturer's manual and its corresponding specifications. The following equations were also used:

$$P\ V^{n} = \text{constant} \qquad (1)$$

$$T_2 = T_1 \left[\frac{P_2}{P_1}\right]^{\left[\frac{n-1}{n}\right]} \qquad (2)$$

$$-w = \frac{n}{n-1}\, m(\ T_1 + 460)\ R \left[\ 1 - \frac{P_2^{(n-1)/n}}{P_1}\right] \qquad (3)$$

where; R = gas constant

$$n = \frac{\ln\ (\ P_2\ /\ P_1)}{\ln\ (v_1\ /\ v_2)} = \frac{1}{1 - \dfrac{\ln\ (T_1\ /\ T_2)}{\ln\ (P_1\ /\ P_2)}} \qquad (4)$$

For the first simulation we created failures in the compressor operation and took readings of all the compressor parameters, the same way as it was done in our experiment. Then these values were entered into our equations and evaluated using the computer program Mathcad (table 1). The possible failures simulated were:

- No failure (test 1)

- Poor ventilation (test 2)
  This was done by blocking air flow from cooling fan (pulley with fan blades) to the intercooler

- Leak between stages (test 3)
  This was done by openning the safety valve located on inlet manifold of the second stage.

Table 1. Results from the first simulation

Parameter	Test no. 1	Test no. 2	Test no. 3
n, polytrpic exponent	1.3172405	1.3538194	1.3520965
n, work (mechanical)	3.9020000	4.0140000	4.0090000
P, work (electrical)	6.8410000	6.8410000	6.8410000
efficiency (mechanical)	0.7800000	0.8030000	0.8020000
efficiency (electrical)	0.7310000	0.7310000	0.7310000
efficiency (overall)	0.5700000	0.5890000	0.5860000
intercooler (effectiveness)	0.1748900	0.0625000	0.1758200

The second simulation was performed by a computer program coded in Q-basic, which calculates the value of the polytropic exponent (n) with the minimun amount of data available and the experimental values of the efficiencies and effectiveness of the intercooler. Then all other parameters related to the compressor's operation were calculated by using selected values of n.

Conclusions

This dissertation has docummented an attempt to assess the operating condition of reciprocating air compressors by quantifying the machine parameters. A theoretical expression for the angular position, velocity, and acceleration of the crank shaft was derived. We also documented the computer based system developed to measure the quantities used to solve the machine parameters and the quantities used to compare them with the calculations.

From these results we can conclude that:

1. The designed mathematical model represents a process influenced by damage (fig. 3).

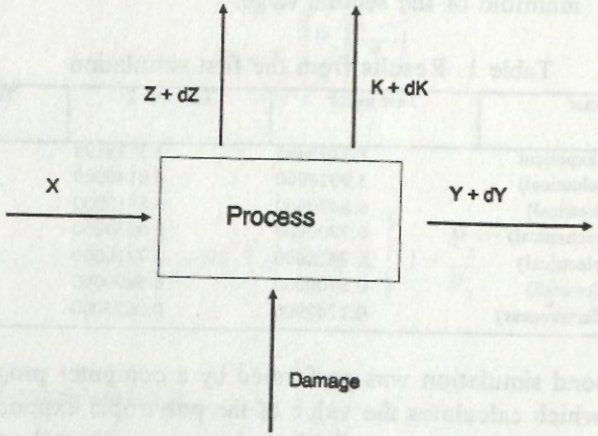


Figura 3. Schematic diagram of the mathematical model

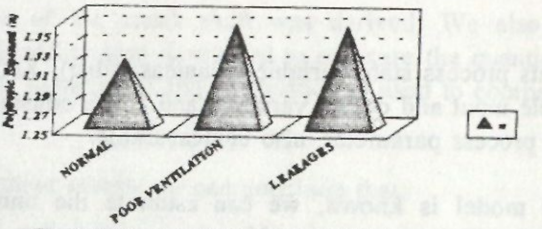
where

$$Y = f(X, K, Z) \tag{5}$$

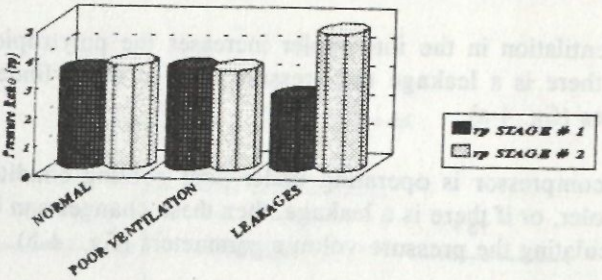
K(t) represents process state variables (unmeasurable), X(t) and Y(t) are measurable input and output variables and Z is a constant or slow time varying process parameter, also unmeasurable.

If a process model is known, we can estimate the unmeasurable process variables, K(t), or unmeasurable process parameters, Z(t), based on the measurable inputs, X(t), and outputs, Y(t), by using state variables or process parameters estimation methods and detecting changes dK(t) or dZ(t).

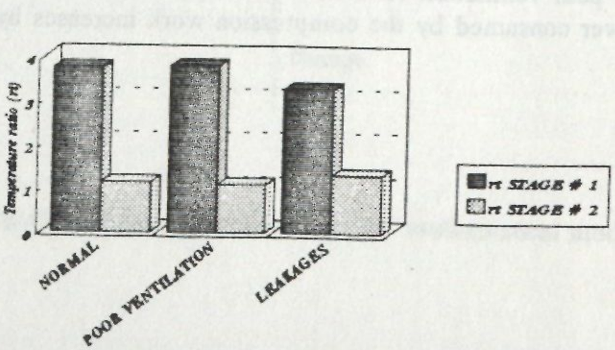
2. Poor ventilation in the intercooler increases the polytropic exponent (n). If there is a leakage the pressure drop in the cylinder chamber increases (fig. 4-a).
3. If the compressor is operating under poor cooling conditions in the intercooler, or if there is a leakage, then these changes can be detected by calculating the pressure-volume parameters (fig. 4-b).
4. Temperatures rise through the second stage decrease approximately 35% in poor ventilation conditions in the intercooler and in this case the power consumed by the compression work increases by 5% (fig. 4c).



Polytropic Exponent
(a)



Pressure Ratio
(b)



Temperature Ratios
(c)

Figure 4. Conclusions