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Prediction of Two StageAir Compressor Characteristic

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ABSTRACT
The paper reports investigation of indicating power input, the poly topic compression index and overall efficiency of two stage air compressor under condition of atmospheric pressure and temperature in Shuwaikh Kuwait.
The volumetric efficiency affected only with compressor dimensions so it will not include in this report.
The experimental procedure will run on G.U.N.T test rig which Test rig occupied with multifunction card and software PCI Lab view software and the current measured values are displayed in the unit process diagram.

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I. INTRODUCTION

Compressors are an important machine in field of mechanical processes. It's almost the only machines used to increase the pressure of gases. Reciprocating compressorsdepends in working principal on:Air is sucked into a cylinder, The trapped air is compressed in a single stroke with a piston, The compressed air is moved onward to a cooler, The pre compressed air moved to the second stage and compressed to the final pressure, and air moved onward to a storage take, the compressed air serves as energy for the tools and instrumentation air.
This paper is triedto focus our attention on how to expect the performance of two stage compressor and how to modify it.

II. LITERATURE SURVEY

2.1 Effect of heat transfer on compressor performance

Heattransfer does not just affect the performance but also thedesign, operation and reliability of compressors.One of the main limitations in the design of compact singlestage compression systems is the inability to control the largetemperatures generated during the compression process. Hencethe need for multi staging.

Temperature also becomes adefining parameter in the operation of many compressors. Inmany cases, the operational pressure ratio needs to be limiteddepending on the inlet temperature, in order to keep thedischarge temperature within safe limits [1].

2.2 Prediction of compressor performance by Simulation process.

Testing of piston failure for prediction of its life is possible with using modeling and analysis software.So that we can reduce the cost of testing. Here the piston is designed in modeling software Creo Parametric2.0 and analysis is done using Ansys 15.0. The results predicted the stresses that will develop during itsrunning condition can be reduced and life of piston can be improved [2].

2.3 A RESEARCH PAPER ON IMPROVING PERFORMANCE AND DEVELOPMENT OF TWO STAGE RECIPROCATING AIR COMPRESSOR .

A two stage reciprocating compressor includesa casing; a first compressing unit disposed in the casing and including a first piston and a firstcylinder, the first compressing unit being driven by a reciprocating motor to linearlyreciprocate the first piston in the first cylinder to suck in and compress gas; a secondcompressing unit disposed in the casing and including a second piston and a second cylinder,the second compressing unit being driven by vibration of the first compressing unit to linearlyreciprocate the second piston in the second cylinder to suck in and compress gas [3].

III. RECIPROCATING COMPRESSOR WORKING PRINCIPAL

The processes in the compressor can beshown in a so-called **p,v diagram**.

In the pressure volume p-v diagram, the pressure in the cylinder isplotted against the related cylinder volume. Figure(1) illustrate the individual phases ofthe compression. As crank rotate the piston moves between top dead center (TDC) and bottom dead center (BDC), cylinder volume will change and alternative the pressure.

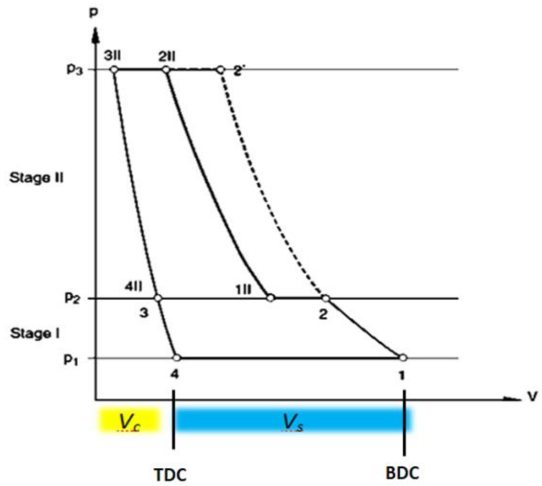

Fig (1) pressure progression on a p,v diagram [3].

3-1 Compression

Starting from point 1, bottom dead center(BDC), the piston compresses the air in thecylinder. With reducing volume, the pressureincreases.

3-2 Expulsion

At point 2 the pressure in the cylinder hasreached the pressure p2 in the pressure line.The pressure valve opens and the compressedair flows into the pressure line.

3-3 Return expansion

At point 3 the piston has reached top deadcenter (TDC) and reverses its direction ofmovement. The pressure valve closes andthe air remaining in the cylinder expandsagain. The pressure drops in cylinder.

3-4 Intake

At point 4 the pressure has dropped back to theambient pressure p1 such that the intake valveopens and fresh air flows into the cylinder. Thisprocess continues until the piston has reachedbottom dead center (BDC). Here, at point 1 theentire process starts all over again.

3-5 Two Stage Compression

If the pressure ratio is increased during singlestage compression, then the back-pressure and temperature of the medium increase . The pressure ratio during compression is limited by the temperature at which the lubricating oil – gas mixture can explode. On staged compression, the medium is cooled between the individualstages Fig (2). In this way the volume losses, the rodforces and the drive power are reduced. Theintermediate cooling effects a reduction in the intake pressure and the intake volume at thesecond stage. In the idealized p-v diagram, the process for the second stage after the intermediate cooling runs isentropic from 1IIto the final pressure 2II. In the case of single stagecompression, the process would runisentropic, without a jump, to the finalpressure 2’. The difference between these twocurves is the saving in work.

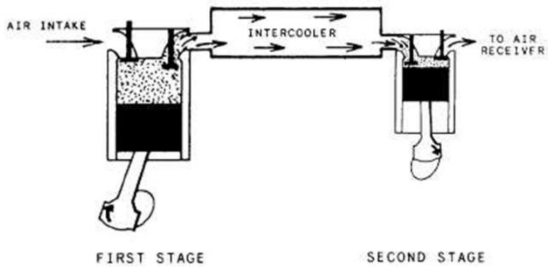

Fig (2) Two stage compressor arrangement

IV. TEST RIG

The process flow diagram can be seen with respect to Fig (3)

Air is induced in to the 1st stage through the pre-cooler tank (9). The first stage compressor (15) will increase air pressure, then the air flow the first cooling tank (14) at which the inlet air flow rate is measured and to reduce the temperature before entering the second stage compressor.

The second compressor will increase air pressure further. After the second stage compression, the output air will flow through the heat exchanger (1) to reduce the temperature before entering the compressed air supply tank, (4).

A pressure release valve,(8) and pressure switch (7), are installed at the compressed air supply tank, (4).once the pressure exceeds 10.8 bars, the pressure switch (7) will cut-off power to motor once pressure in air supply tank, (4)reaches the set pressure (max 10 bars) .the pressure switch must be reset by exchange its position.

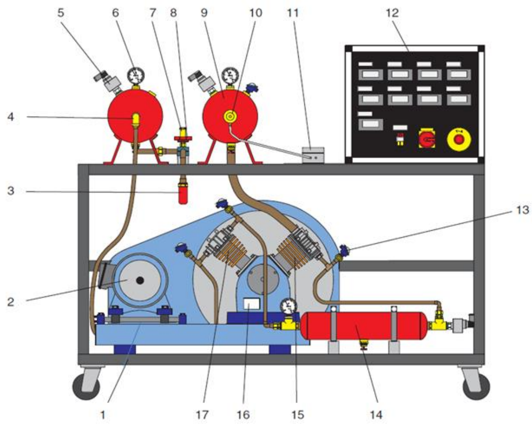

Fig (3) Test rig [4]

V. COMPRESSOR CHARACTERISTIC

5-1 Capacity of the compressor

Compressor capacity is the mass of air delivered per second. Sometimes it is expressed as free air delivery, and is the volume of air delivered measured at ambient conditions.

Referring to figure (1)

$V_L = V_s + V_c$(1)

where,

V_L cylinder volume m^3 ,

V_s swept volume m^3 ,

V_c clearance volume m^3

d, cylinder bore m

L , stroke length m

$$V_s = \frac{\pi d^2}{4} L \qquad (2)$$

The clearance volume expressed as percentage of stroke volume .

Mass of air in the cylinder at any point can be calculated by applying the characteristic gas equation

$$m_c = \frac{p_c V_c}{RT_c} \qquad (3)$$

$$m_c = \frac{p_2 V_c}{RT_2} \qquad (4)$$

Mass of air delivered per cycle

$m = m_L - m_c$(5)

Compressor capacity

$$\dot{m} = ze\frac{N}{60}m \qquad (6)$$

where,

$\dot{m}$mass flow rate of air kg/s

z, number of cylinders

e, effective number of cycles per revolution

N compressor speed, rpm

m, mass of air delivered per cycle kg

5-2 Indicated power input

Referring to figure (1)

For single cylinder indicated work input per cycle equal area of the cycle 1-2-3-4-1 and omitting detail of derivation

$$IP = \frac{n}{n-1}\frac{\dot{m}}{\rho}RT_1\left[\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} - 1\right] \qquad (7)$$

$where,$

n Index of polytropic compression

ρ, molecular mass of air = 29 kg.mol/kg

R the gas law constant = 8314.34 j/kg mol .k

For two stage compressor the intermediate pressure chosen to minimize the total work input to both stages after derivation we get the intermediate pressure

$$p_2 = \sqrt{p_1 \times p_3} \qquad (8)$$

Thus the condition for minimum work input is that the pressure ratio in each stage is the same and that the intercooling is complete.

Total power input = 2 x power required for one stage

$$Total\ IP = 2 \times \frac{n}{n-1}\frac{\dot{m}}{\rho}RT_1\left[\left(\frac{p_3}{p_1}\right)^{\frac{n-1}{2n}} - 1\right] \qquad (9)$$

5-3 Index of polytropic compression

The value of the polytropic index of compression, n depends on the rate of heat loss from the compressor cylinder. If the cylinder is perfectly insulated the compression will follow an adiabatic process and $n=\gamma=1.4$

The polytropic index n can be determined as follows :

$$n = \frac{1}{1-\left[\frac{log\left(\frac{T2}{T1}\right)}{log\left(\frac{p2+p_{atm}}{p_{atm}}\right)}\right]} \qquad (10)$$

5-4 Overall efficiency

Most often the compressors are driven by electric motors and the power transmitted through a belt drive or a gear box. The power input to the shaft will be larger than the indicated power and the electric power will be larger than the power input to compressor shaft because of frictional losses in bearings and other moving pans. Overall efficiency can be determined as follows [6] :

$$\eta_{overall} = \frac{Indicated\ \ power\ \ input}{Electrical\ \ power\ \ input} \times 100\% \qquad (11)$$

VI. EXPERIMENTAL PROCEDURE

6-1 startup ;

- Switch on PCI and open ET500 software and choose system diagram.
- Switch on compressor and allow the system to run until a constant pressure p_3 has built up, set

the desired final pressure p_3 with the bleeder valve.

- Take print screen and all measured values recorded.

6-2 Measured values

All measured values are listed on the fig (4)

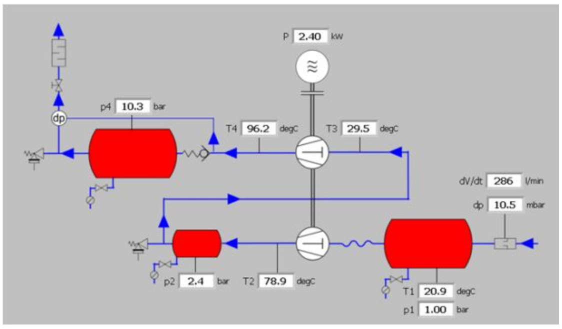

Fig (4) Measured values [4]

VII. Results

7-1 Polytropic index *n* calculated from equation(10)

$$n = \frac{1}{1-\left[\frac{\log\left(\frac{T_2}{T_1}\right)}{\log\left(\frac{p_2+p_{atm}}{p_{atm}}\right)}\right]} \quad (10)$$

$$n = \frac{1}{1-\left[\frac{\log\left(\frac{87.9+273}{20.9+273}\right)}{\log\left(\frac{240000+101300}{101300}\right)}\right]} \quad (10)$$

n, = 1.2035

7-2 Total Indicated Power from equation 9 :

$$Total\ IP = 2 \times \frac{n}{n-1}\frac{\dot{m}}{\rho}RT_1\left[\left(\frac{p_3}{p_1}\right)^{\frac{n-1}{2n}} - 1\right] \quad (9)$$

$$Total\ IP = 2 \times \frac{1.2035}{0.2035}\frac{\rho \times 0.004766}{\rho}286.7 \times 293.3\left[\left(\frac{10.3}{1}\right)^{\frac{0.2}{2.4}} - 1\right]$$

$$Total\ IP = 1901.49\ w$$

7-3 Overall Efficiency

Overall Efficiency calculated from equation (11)

$$\eta_{overall} = \frac{Indicated\ \ power\ \ input}{Electrical\ \ power\ \ input} \times 100\%$$

$$\eta_{overall} = \frac{1901.49}{2400} \times 100\%$$

$$\eta_{overall} = 79.22\ \%$$

VIII. CONCLUSION

- The polytrophic index n=1.2035 isgood value and convenient since inter-stage cooled by air.
- Total indicated power input is high since the inter stage pressure p_2 lower than the optimum pressure (3.2bar).
- Overall Efficiency 79.22 % is low because friction losses high and intermediate pressure not optimum pressure.

RECOMMENDATION

Its recommended to carry out a lot of medication to increase overall efficiency of two stage compressor specially in clearance volume to reach the optimum intermediate pressure which in turnincrease the overall efficiency.

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