ENERGY EFFICIENT CONTROL FOR COMPRESSED AIR WITH STEP MODULATION TECHNIQUE

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Dedication to my beloved Mother, HEE AH FONG, and my wife, Rajeswari Supramanian whom support me, physically, mentally and emotionally, throughout my Master's study.

For my siblings and friends, appreciate your encouragement and help. To all my lecturers, you are my inspiration for today and future time. Thank you everyone and only the universal supreme can bestow just reward to all of you.

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ABSTRACT

The compressed air system is not only an energy intensive utility but also one of the least energy efficient. Over a period of time, both performance of compressors and compressed air system reduces drastically. The causes are many such as poor maintenance, wear and tear of equipment. The thesis presents the Energy efficient control for compressed air by using step modulating technique, which would optimize the energy consumption for the compressed air. The proposed technique has been tested on actual industrial consumer site. By adding the VSD “Variable Speed Drive” to the conventional control compressed air and by regulation the prime mover speeds on unloading cycle with step modulation technique it is discovered that the electrical energy consumption of the compressed air system has been optimized. This will give a prominent saving to the consumer in term of utility bill. From the analysis results, it showed that the saving of 22% can be achieved.

ABSTRAK

Pemampat angain adalah sebuah jentera yang mengunakan tenaga elektrik yang amat tinggi pada kecekapan yang terlalu rendah. Jika ia dinilai dari segi operasi peralatan pada satu jangka masa tertentu, dari segi kecekapan peralatan dan sistem pemampat angain akan berkurang secara mendadak. Ini adalah disebabkan kerana penyelenggaraan yang tidak teratur serta kehausan pada bahagian peranti mekanikal. Thesis ini membentangkan kecekapan pegawalan tenaga untuk pemampat angain dengan mengunakan pendekatan pengurangan beperingkat, ia secara terus akan meningkatkan kecekapan pemampat serta mengurangkan pengunaan tenaga. Cara yang dicadangkan ini telah diuji disalah sebuah industri pegguna pemampat angain. Dengan pemasangan sebuah pemacu pengawal kelajuan “Variable Speed Drive” secara terus kedalam pemampat angain yang mengunakan pengawal biasa, dimana kelajuan pemacu utama dikurangkan pada waktu pemampatan tidak berbeban, dengan cara pengurangan yang dicadangkan didapati pengunaan tenaga elektrik dapat dikurangkan secara terus. Ini bukan sahaja memberikan manafaat kepada pengunaa dari segi peningkatan kecekapaan peralatan tetapi juga tenaga elektrik. Daripada analisis keputusan didapati pegurangan tenaga sebanyak 22% telah dicapai.

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LIST OF ABBREVIATION

R.O.I		Return Of Investment
D.O.E		Department Of Energy U.S
bhp		Load Horsepower
H.P.		Horse Power
Pmin	-	Minimum Power
Pmax	-	Maximum Power
VSD		Variable Speed Drive
R.P.M		Revolution Per Minutes
Sr		Synchronous Slip factor
Bar		Pressure Unit
Psig		pressure unit in per square inch gauge
Kwatt		Electric unit kilo watt

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CHAPTER 1

INTRODUCTION

Generally the Air compressor is a mechanical energy producer, it was power by electric Motor to generate, store and distribute energy in the form of compressed air for use throughout a plant. In a compressed air system, a single set of compressors can supply power to machines all over the plant, thus eliminating the need for numerous and dispersed electric motors. This advantage must be balanced against the relative poor energy efficiency of compressed air systems, which can be as low as 20% [1], when leaks and part-load control losses are taken into account. A recent survey by the U.S. Department of Energy showed that for a typical industrial facility, approximately 10% of the electricity consumed is for generating compressed air. For some facilities, compressed air generation may account for 30% or more of the electricity consumed [2]. Compressed air is an on-site generated utility. Very often, the cost of generation is not known; however, some companies use a value of 18-30 cents per 1,000 cubic feet of air.

On a national scale, air compressors rank only behind pumps in terms of industrial motor drive electricity consumption. Thus, increasing the efficiency of compressed air systems can result in significant energy savings.

1.1 Compressor Overview

Compressed air is a form of stored energy that is used to operate machinery, equipment, or processes. Compressed air is used in most manufacturing and some service industries, often where it is impractical or hazardous to use electrical energy directly to supply power to tools and equipment. Powered by electricity, a typical air compressor takes approximately 7 volumes of air at atmospheric conditions, and squeezes it into 1 volume at elevated pressure (about 100 psig, [7 bars]). The resulting high pressure air is distributed to equipment or tools where it releases useful energy to the operating tool or equipment as it is expanded back to atmospheric pressure [1], In the compression process 1 bar atmospheric conversion to 7 bars with excessive heat and through the subsequent cooling of the air back to ambient temperatures, heat and moisture, are released as illustrated in Figure 1.0.

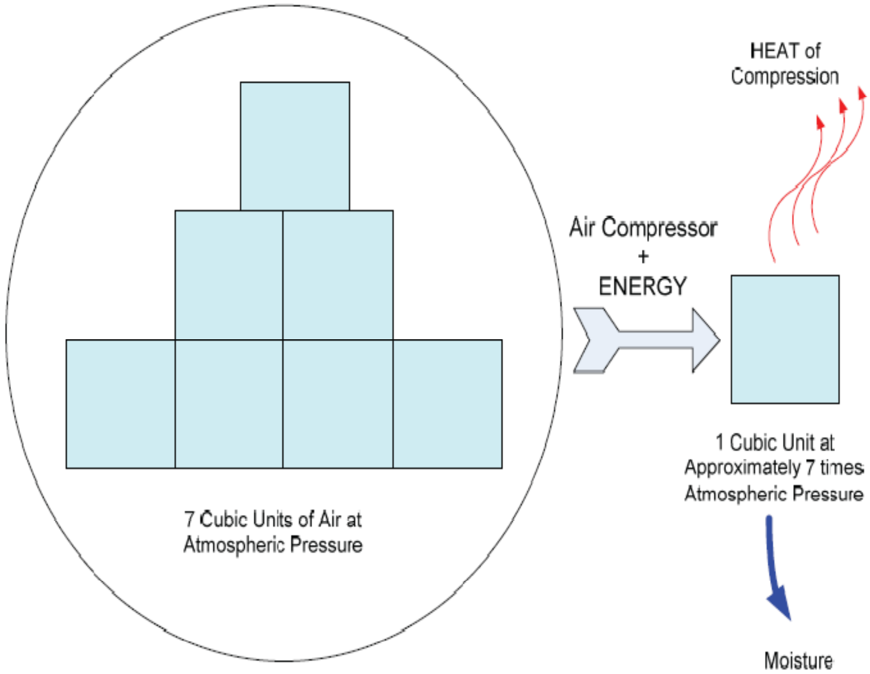

Figure 1.0 Conversion of Atmospheric Air into Compressed Air

Recovered heat from the air compressor can potentially be used as an energy efficiency measure for other processes, such as space and water heating. Depending on the application, excessive moisture in compressed air needs to be managed as it can cause problems with piping (corrosion) and end use equipment.

Figure 1.1 illustrates the typical losses associated with producing and distributing compressed air [1]. Assuming 100 HP energy input, approximately 91 HP ends up as losses, and only 9 HP as useful work. In other words, about 90% of the energy to produce and distribute compressed air is typically lost.

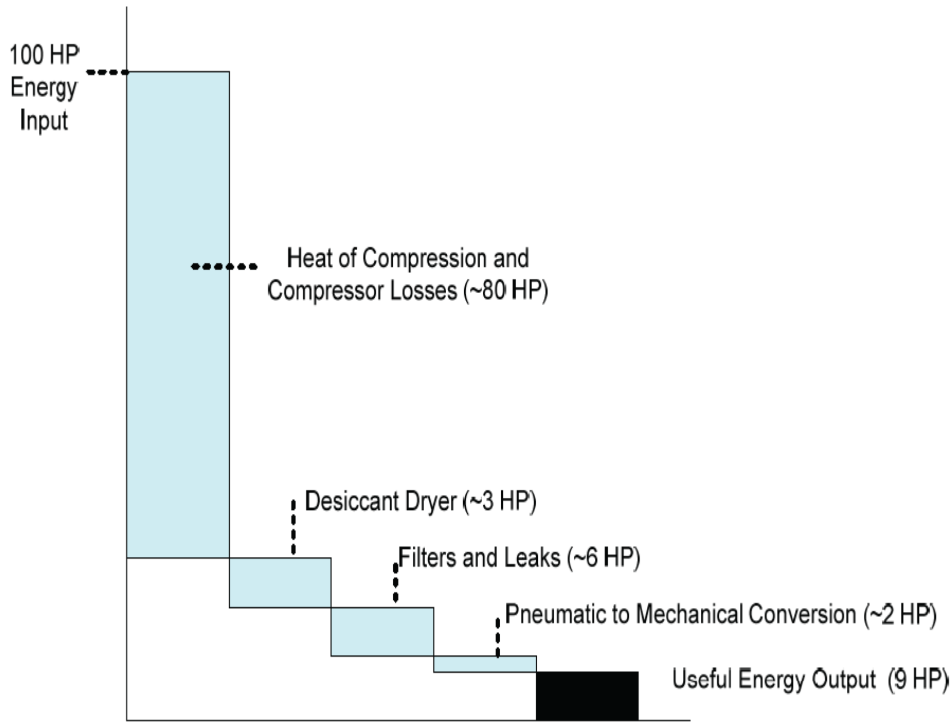

Figure 1.1 Compressed Air Energy Input and Useful Energy Output (Adapted from Northwest Energy Alliance)

1.2 Compressor System Overview

Compressed air systems consist of a number of major subsystems and components. Compressed air systems can be subdivided into the Supply and Demand side.

The Supply side includes compressors, air treatment and primary storage. A properly managed supply side will result in clean, dry, stable air being delivered at the appropriate pressure in a dependable, cost effective manner. Major compressed air supply subsystems typically include the air intake, air compressor (fixed speed and/or variable speed), after cooler, motor, controls, treatment equipment and accessories.

Controls serve to adjust the amount of compressed air being produced to maintain constant system pressure and manage the interaction between system components. Air filters and Air dryers remove moisture, oil and contaminants from the compressed air. Compressed air storage (wet and dry receivers) can also be used to improve system efficiency and stability. Accumulated water is manually or automatically discharged through drains. Optional pressure controllers are used to maintain a constant pressure at an end use device.

The Demand side includes distribution piping, secondary storage and end use equipment. A properly managed demand side minimizes pressure differentials, reduces wasted air from leakage and drainage and utilizes compressed air for appropriate applications. Distribution piping systems transport compressed air from the air compressor to the end use point where it is required. Compressed air storage receivers on the demand side can also be used to improve system pressure stability.

As a rule of thumb, for every horsepower (HP) in the nameplate capacity, the air compressor will produce approximately 4 standard cubic feet per minute (scfm).

A simplified diagram illustrating how some of the major components are connected is shown in Figure 1.2.

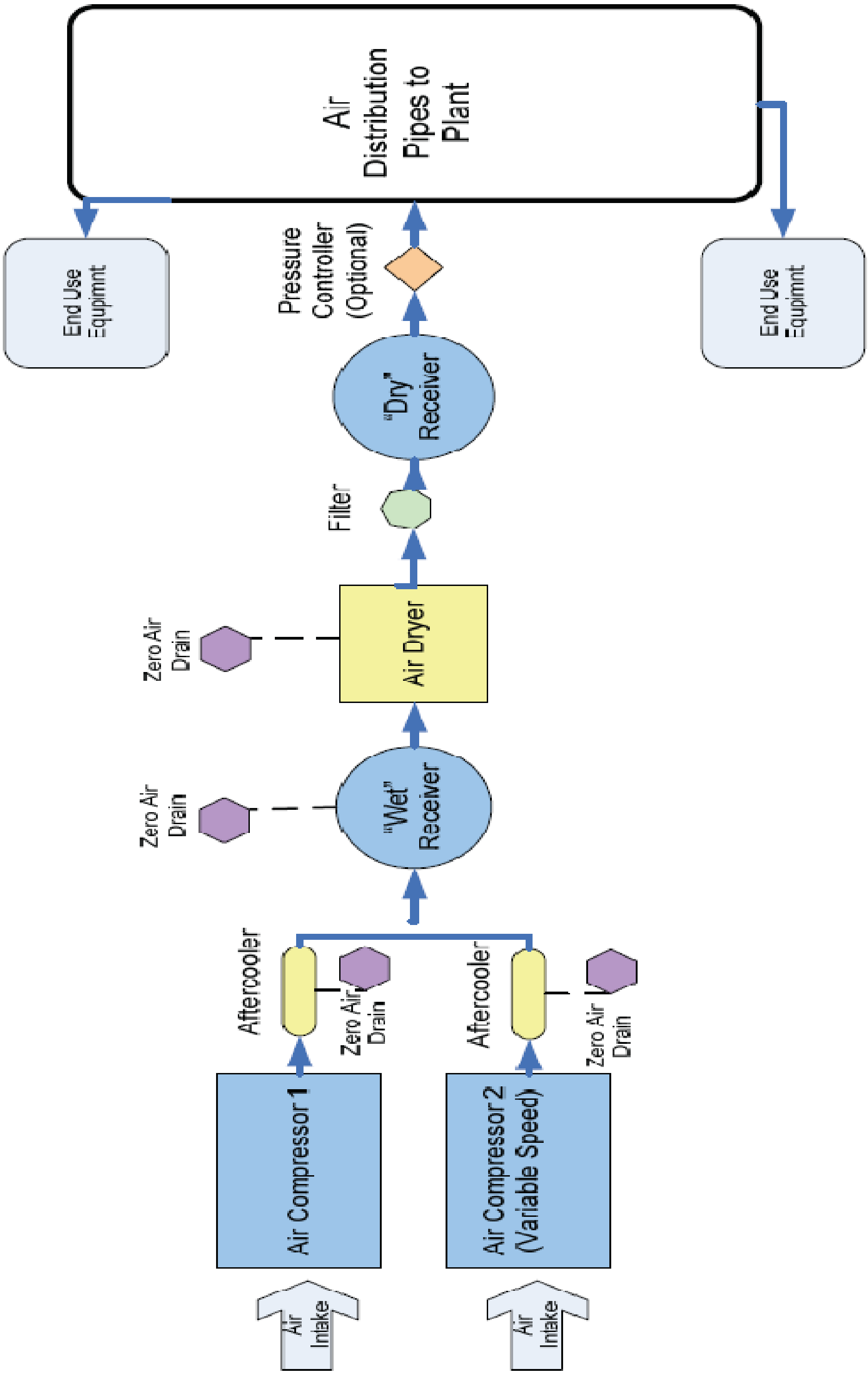

Figure 1.2 Common Air Compressor System Components

Compressed air is used for a diverse range of commercial and industrial applications. As it is widely employed throughout industry, it is sometimes considered to be the ‘‘fourth utility’’ at many facilities.

It has been common practice in the past to make decisions about compressed air equipment and the end uses based on a first cost notion. Ongoing energy, productivity and maintenance costs need to be considered for optimal systems. In other words, best practice calls for decisions to be based on the life cycle cost of the compressed air system and components.

Improving and maintaining peak compressed air system optimization requires addressing both the supply and demand sides of the system and understanding how the two interact.

Optimal performance can be ensured by properly specifying and sizing equipment, operating the system at the lowest possible pressure, shutting down unnecessary equipment, and managing compressor controls and air storage. In addition, the repair of chronic air leaks will further reduce costs.

For a typical compressed air end use, like an air motor or diaphragm pump, it takes about 10 units of electrical energy input to the compressor to produce about one unit of actual mechanical output to the work.

For this reason other methods of power output, such as direct drive electrical motors, should be considered first before using compressed air powered equipment. If compressed air is used for an application, the amount of air used should be the minimum quantity and pressure necessary, and should only be used for the shortest possible duration. Compressed air use should also be constantly monitored and reevaluated.

1.3 Type of Air compressor

There are two basic types of air compressors:

i) Positive displacement, and
ii) Dynamic.

i) Positive Displacement.

In the positive displacement type, a specified quantity of air is trapped in a compression chamber and the volume which it occupies is mechanically reduced, causing a corresponding rise in pressure prior to discharge. Rotary screw, vane and reciprocating air compressors are the three most common types of air positive displacement compressors found in small and medium sized industries.

ii) Dynamic.

Dynamic air compressors include centrifugal and axial machines, and are used in very large manufacturing facilities. These units are beyond the scope of this document.

Here will discuss only for positive displacement compressor, the dynamic unit is not popular or common equipment use throughout industries in Malaysia.

1.3.1 Positive Displacement Compressor

A bicycle pump is the simplest form of a positive displacement compressor, where air is drawn into a cylinder and is compressed by a moving piston. The piston compressor has the same operating principle and uses a piston whose forward and backward movement is accomplished by a connecting rod and a rotating crankshaft. If only one side of the piston is used for compression this is called a single-acting compressor. If both the piston's top and undersides are used, the compressor is double acting.

The pressure ratio is the relationship between absolute pressure on the inlet and outlet sides. Accordingly, a machine that draws in air at atmospheric pressure 1 bar (a) and compresses it to 7 bar overpressure works at a pressure ratio of (7 + 1)/1 = 8. Sample positive displacement compressed air illustrated in Figure 1.3 Twin rotary screw compressor layout [3]. It is a most common compressor which has in service throughout Malaysia manufacturing industries in present day.

The principle for a rotating displacement compressor in twin screw form was developed during the 1930s, when a rotating compressor with high flow rate and stable flow under varying pressure conditions was required.

The twin screw element's main parts are the male and female rotors, which rotate in opposite directions while the volume between them and the housing decreases. Each screw element has a fixed, build-in pressure ratio that is dependent on its length, the pitch of the screw and the form of the discharge port. To attain maximum efficiency, the build-in pressure ratio must be adapted to the required working pressure.

The screw compressor is generally not equipped with valves and has no mechanical forces that cause unbalance. This means it can work at a high shaft speed and can combine a large flow rate with small exterior dimensions. An axial acting force, dependent on the pressure difference between the inlet and outlet, must be overcome by the bearings. The process of air compression has illustrated in Figure 1.4 [4].

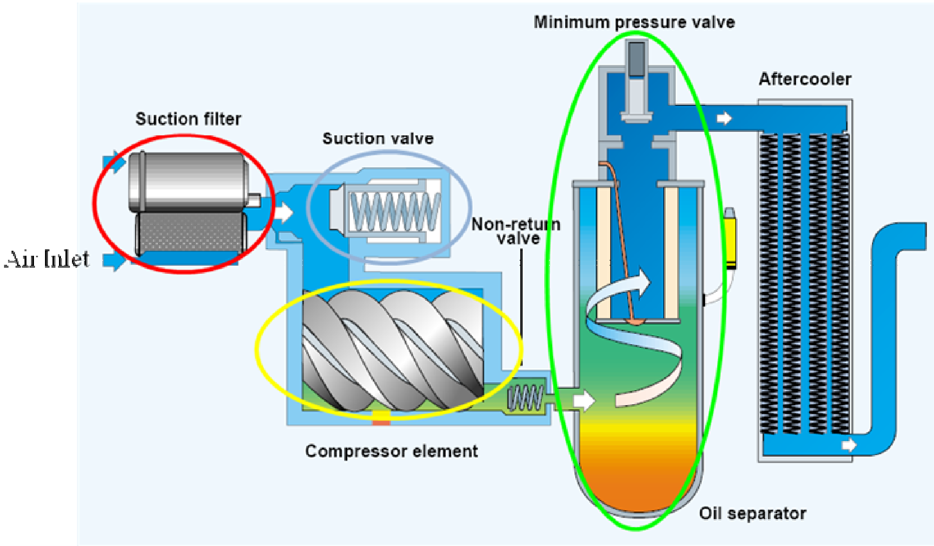

Figure 1.3 Shown twin screw air compressor general layout

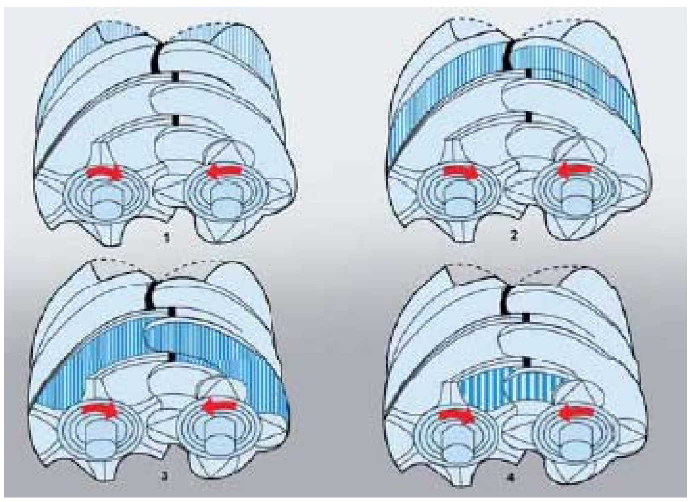

Figure 1.4 Shown Compressed Air process in twin screw compressor

1.4 Compressed Air control overview

As air systems seldom operate at full load all of the time, the ability to efficiently control flow at part loads is essential. Consideration should be placed to both compressor and system control selection as they are important factors affecting system performance and energy efficiency. For the positive displacement compressed air the most common method to control was load/unload, this control mode is sometimes called online/offline control.

It keeps the motor running continuously, but unloads the compressor when the discharge pressure is adequate by closing the inlet air suction valve. Unloaded rotary screw compressors typically consume 50% - 75% of their full load power demand, while producing no useful compressed air output. The detail compression about the control method will discuss in literature review.

1.5 Estimation of energy cost

Compressed air is one of the most expensive sources of energy in a plant. The over-all efficiency of a typical compressed air system can be as low as 10%-15%. For example, to operate a 1-horsepower (hp) air motor at 100 pounds per square inch gauge (psig), approximately 7-8 hp of electrical power is supplied to the air compressor. To calculate the cost of compressed air in your facility, use the formula shown below [2]:

$$\text{Cost (\$)} = \frac{(\text{bhp}) \times (0.746) \times (\text{\# of operating hours}) \times (\text{\$/kWh}) \times (\text{\% time}) \times (\text{\% full-load bhp})}{\text{Motor Efficiency}}$$

Where:

bhp—Motor full-load horsepower (frequently higher than the motor nameplate horsepower—check equipment specification)

0.746—conversion between hp and kW

Percent time—percentage of time running at this operating level

Percent full-load bhp—bhp as percentage of full-load bhp at this operating level

Motor efficiency—motor efficiency at this operating level.

Assumes the compressor average loading is 65% of full load, over the first ten years of life of a typical air cooled compressor as shown in figure 1.5, with two shift operation, the operating cost (electricity and maintenance) will equal about 88% of the total lifetime cost. The cost of the original equipment and installation will account for the remaining 12% [5].

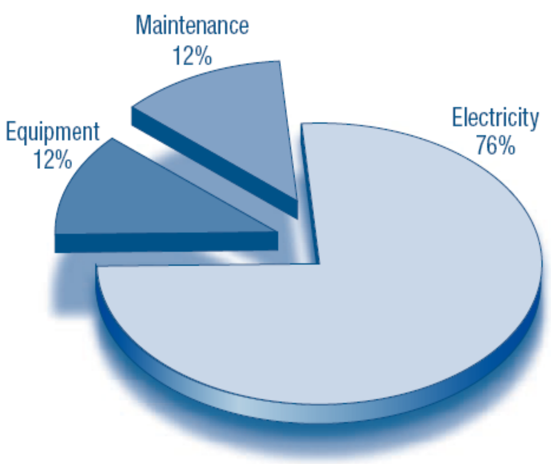

Figure 1.5 Typical Lifetime Ownership Cost of Compressed Air Systems.

1.6 Problem Statement

The discussion on problem statement will base on load graph analysis as illustrated in Figure 1.6. This load graph has been logged at one of the customer (Jayaplastic Industries (M) Sdn. Bhd.), 100 H.P (75Kwatt) Compressed air. To start to analysis load profile graph, should have a good understanding on the behavior of compressed air prime mover (Electric Motor). Naturally the asynchronous motor is non liner torque characteristic due to rotor construction [6]. It has differences compare to DC electric motor, where this motor proportionally liner to current versus torque. On the asynchronous motor the stator rotating magnetic field speed and rotor speed had differentiate by slip factor (S_r)[7]. Where the slight drop on slip (S_r) factor of synchronous speed from rated the current will increased tremendously [6]. The motor not only became inefficient on power consumption, but as speed decreases it will proportionally affects the compressed air performance. For the compression process speed will determined the loading cycle time period, slower the speed the longer the time will consume to generated 7 bars air pressure. Usually the pressure high and low setpoint differentiated by 1 Bar. For unloading cycle time period, will base on setting of lowest point to start compression process versus demanded air volume discharge. This has illustrated at the same load graph by overlapping of pressure graph on to compare the affect lowest set point and electric motor performance and energy wastage area. The detail discussion will illustrate in further discussion.

1.6.1 Load graph analysis

This power data has logged from 75Kwatt power electric motor for Sullair compressed Air by using KEW6310 power quality analyzer. The logged data has converter by KEW PQA MASTER Ver2.04 software to graph form for further analysis. The motor detail has listed:

Rated Power (kW) = 75

Rated Current (Amp) = 147

Rated R.P.M = 1430

Rated Voltage (Volt) = 415

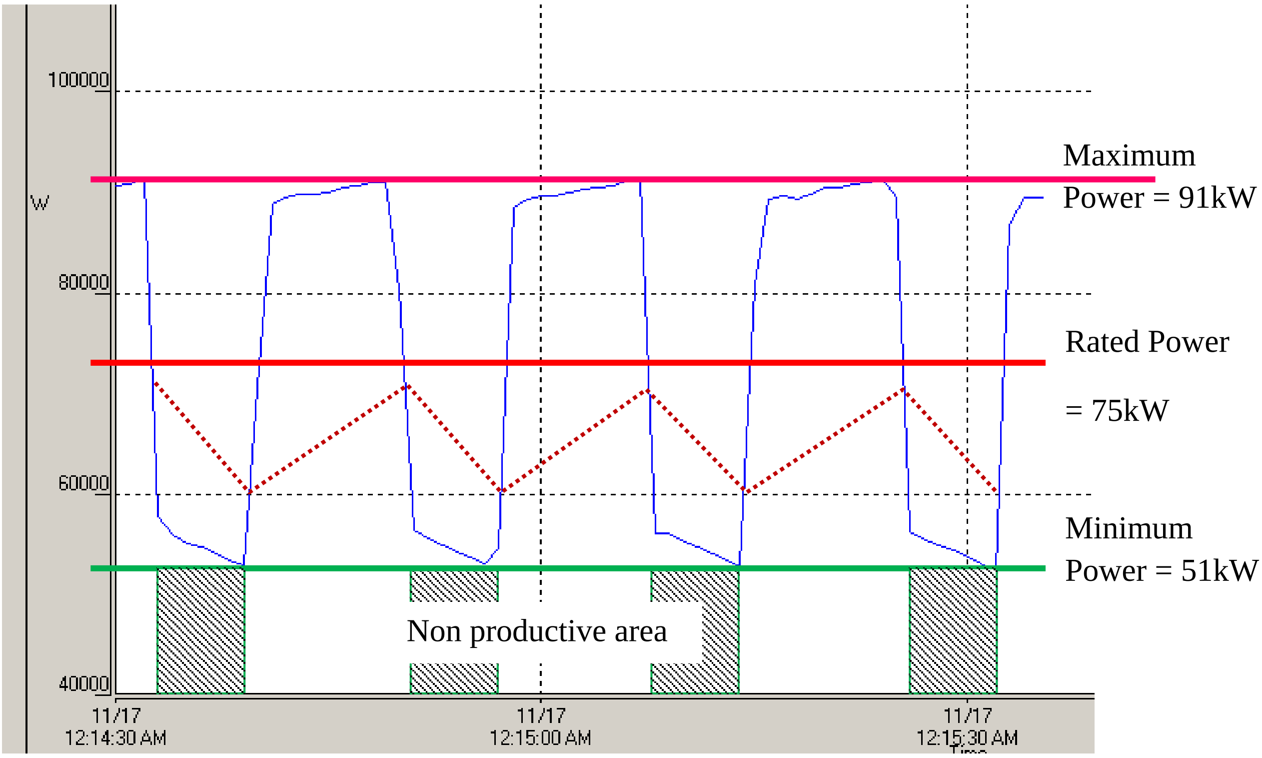

Figure 1.6 Load Graph Cut view on real data

There is few lines had been drawn onto load graph to indicate the rated power, minimum power and maximum power consume by the electric motor of sullair compressed air. Practically the energy consume by the motor should equal or less to rated power, but if the observation goes deeply with the guide of references line on loading period the power consume are more than rated nearly to pull out point, and the power consume on the unloading time nearly 70% from the rated power. The evaluation analyses for the prime mover rated power either wastage on loading period will not discussion. That is not our point of analysis, this analysis going with existed prime mover where try to find room of the potential saving.

Obviously there are existences of non productive area, with some amount power was consume. From this consumption point of power, we could pull down to optimum point by regulating the speed. The power consumption for entire system will reduce proportionally.

This is not only given energy saving, if it has compared to existing system it has also increased the compressor efficiency. To do so there is device call VSD (Variable speed Drive) need to be employ into existing system. The next step is to choose appropriate of technique to regulate the speed, with the following question rise “how to regulate the speed?”. To answered the question is a challenge where need to have a proper analysis to sure the control does not fail on the system reliable operation. This will further discussed in chapter 2.

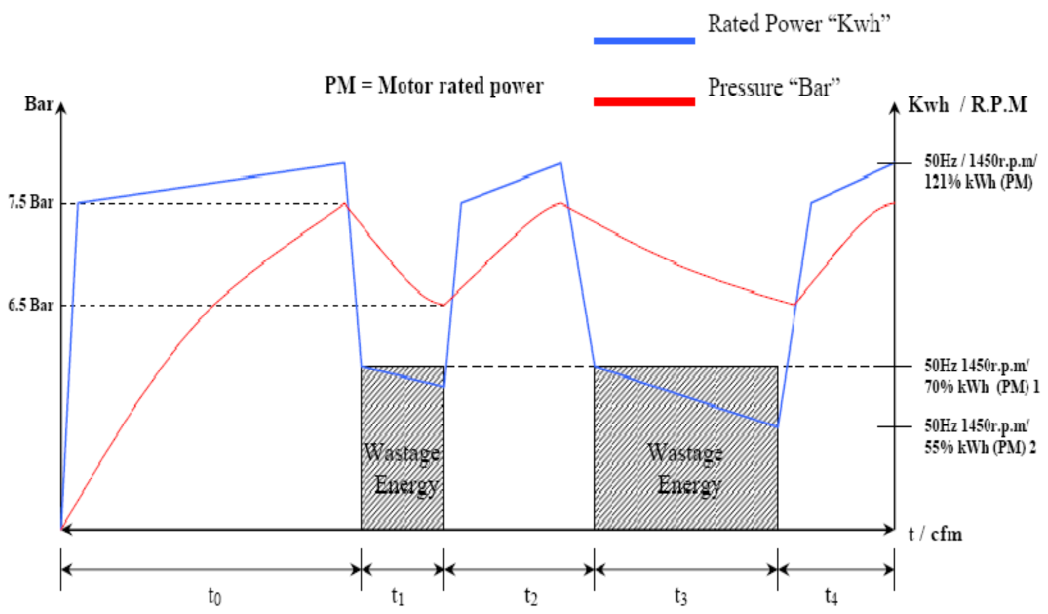

Figure 1.7 Load graph and Air pressure combination

1.7 Objective

The objective of this project:

a) To Study Air compressor control system, unload cycle and Electrical load characteristics. To identify the potential energy saving in air compressor system.
b) To propose and implemented the Low cost control strategy for Air compressor to minimize energy consumption for *existing conventional method control air compressor.*

c) To analysis the impact of the propose energy efficient control on energy saving as well as the Return of Investment (ROI).

1.8 Project scope

The proposed energy solution going too implemented at one of our customer place located at Kota kemuning Shah Alam, PPR extrusion pipe manufacture (George Fisher (M) Sdn. Bhd). The 15H.P compressed air, brand Airman going to emphasis the propose method to review practical result on the energy consumption. The detail result will discuss on chapter 4. As show in the figure 1.8 was the chosen compressed air. As discussed early we are going to regulate the prime mover speed to achieve the energy saving. This project focus is not going to refurbish or redesign the existing system we just want to add in the VSD and pressure sensor to regulate the prime mover speed on unloading period with chosen appropriate control method through the initial analysis. The final control method will discuss in chapter 3.

Figure 1.8 15H.P Air compressor brand ‘AIRMAN”

1.9 Significance of the project

This project is not only will focus on saving but throughout the analysis process, consumers have a chance of awareness on compressed air operation efficiency and system arrangement. For most case those already have awareness they may need little idea to make the system became slightly efficient compare to present in operation. Even the saving may not significant to low demanded manufacture process, but it significant for those manufacturing process use the compressed air energy 100%.

1.10 Organization of the reports

In general, this report mainly consists of five main chapters; introduction, literature review, methodology and implementation of new control method to compressed air, finally other two chapters will cover on Final results and conclusion and future work of improvement.

The chapter one discussed the research project in collectively. This chapter explained the crucial aspect of the research work such as background studies, objectives, research scopes and methodology as well the thesis outline will also be discussed finally.

The chapter two completely dedicated to literature review, which will review about available control methodology and energy consumption from point of electrical aspect, on point mechanical aspect restructure of storage tank redesign this will discussed briefly the complete theory will attach in appendix, problem on the existing system of prime mover, and implementation step modulation technique with consequent problem. To have more reliable control more study required to ensure the objective of project able to meet.

The chapter three has dedicated to review on implementation technique and step modulating method. In this chapter discussion will completely on control equipment, speed regulation technique, sampling time and data analysis by the controller.

The chapter four was dedicated to analysis the result of the implementation technique, this is too sure give significant improvement on energy saving, this chapter will enclosed with conclusion.

The final chapter fully dedicated to brief to the future work and improvement to this project, to sure it has can useable for all type compressor with more reliable control.

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