Case Study 137

Compressed air costs reduced by automatic control system

Vehicle production line

Case Study Objective

To demonstrate the energy and cost savings of an automatic system to control the operation of air compression plant.

Potential Users

Any compressor house containing three or more compressors.

Investment Costs (1991)

Total system-related costs were £31,700, of which £20,000 were capital costs (1991 prices).

Savings Achieved

600,000 kWh (2,100 GJ/year, worth £24,000/year (1991 prices).

Payback Period (1991)

1.3 years (direct benefit from controller); eight months (taking account of consequent leakage reduction).

Reduced Costs and Improved Payback at 1998 Prices

Since the writing of this case study in 1991, the required investment costs have fallen significantly, such that had the controller been installed in 1998 instead of 1991, the capital cost would be reduced from £20,000 to £2,973 plus £600 for installation of the basic control. This would reduce the payback (direct benefit from the controller) to less than 3 months, compared to 1.3 years in 1991, and is despite the lower cost of electricity to Land Rover in 1998.

Case Study Summary

The installation of a computerised compressor control system has reduced compressed air generation costs by 18.5% at Land Rover. The system was installed and has been operated with no disruption to production. The overall costs for the system produced a payback period of 16 months which could be replicated on most compressed air systems utilising three or more compressors. This presents a simple and reliable opportunity for large compressed air users to reduce their electrical costs.

Further savings of 20% were also obtained by repairing compressed air leaks. This potential exists for most compressed air users and represents an immediate cost saving opportunity. It was highlighted at Land Rover by the new control system, which quantified the amount of air being used out of hours.

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BEST PRACTICE PROGRAMME

ENERGY EFFICIENCY

Introduction

In the UK, the annual cost of energy used to generate compressed air, for use as a utility, is estimated to be £225 million. It is estimated that around 27% of this energy could be saved by a combination of measures which include better control of the air compressors.

Amongst the inefficiencies that commonly occur are:

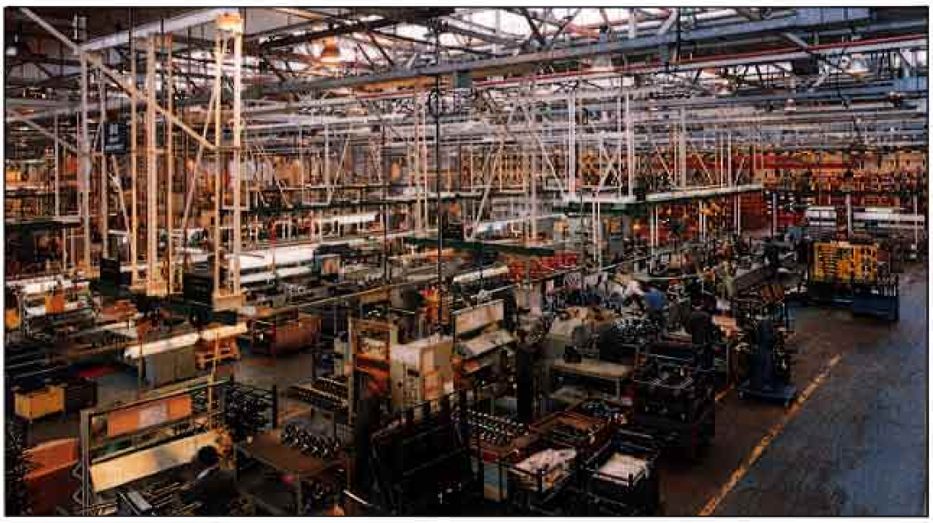
- generation of air at a pressure above that needed;
- use of an incorrect combination of compressors to meet the air demand;
- use of compressors whose volumetric efficiencies have deteriorated unknown to the operators.

In addition many operators do not regularly monitor either the volume of air being used or the energy consumption.

This case study shows how an automatic control system overcame all the inefficiencies listed above.

Background

Air compressors have high levels of electricity consumption and those on the Solihull site are typically driven by some of the largest motors in that plant. As less than 10% of the energy they consume is converted into useful work, the remainder being lost in the form of heat and leaks, compressed air provision is the most expensive form of energy use at the works.

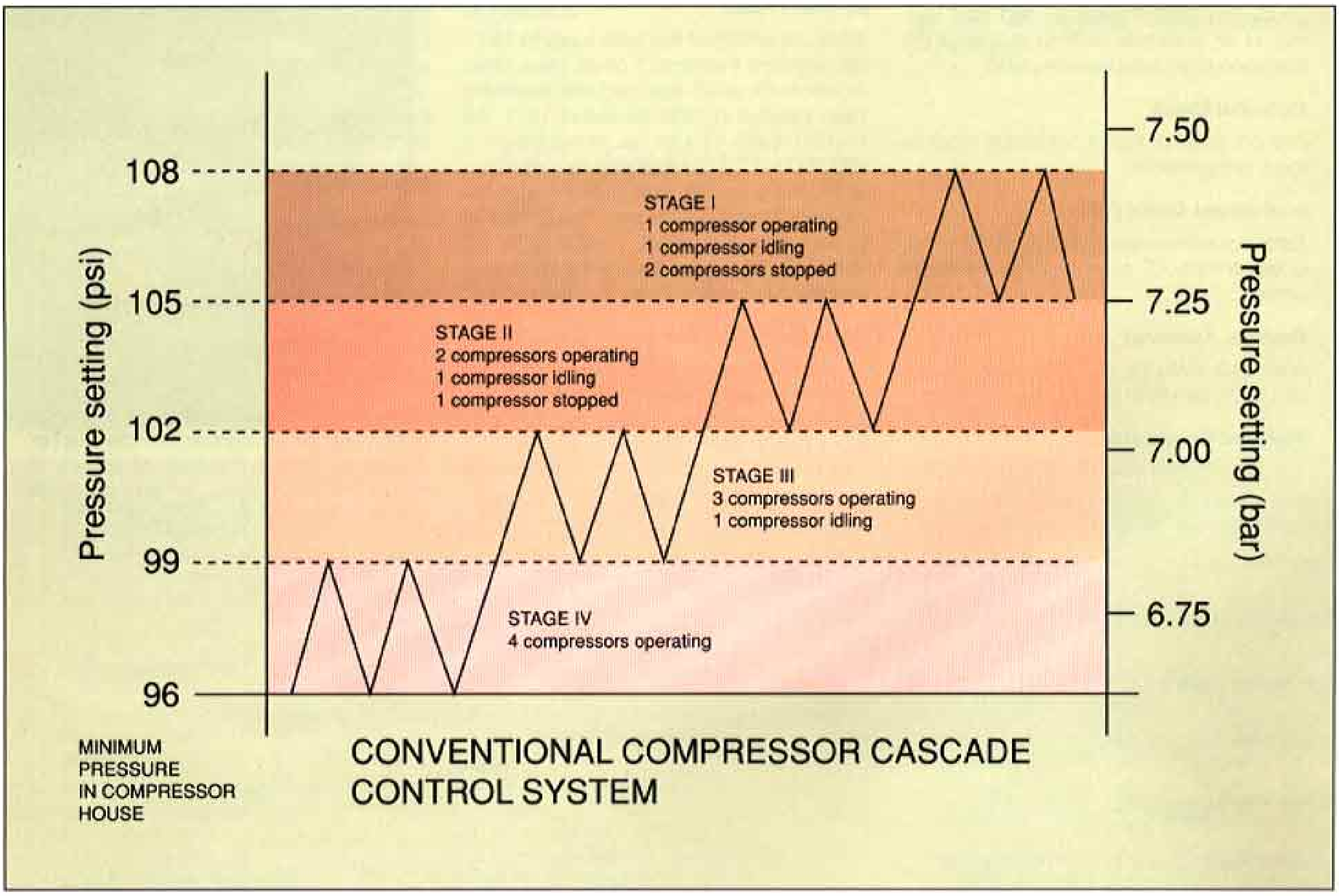


Production area

Land Rover at Solihull has three main manufacturing areas. In the East works, manned by a mixture of shift patterns, the company manufactures bodies and transmissions. This works, where the new compressor control system was installed, has its own compressed air service. Although this service can be connected to the other works, it is run independently.

The compressor house contains six reciprocating compressors: four rated at 0.47 m^3/s (1,000 cfm) and two at 0.94 m^3/s (2,000 cfm). Each compressor has its own kWh meter and the total air generated from all compressors combined is measured and recorded on an orifice plate flowmeter. This flowmeter has the facility to give a 24-hour or 7-day recording of generated air pressure and total flow rate, which has proved very useful for the study.

The previous control system deployed conventional pressure cascade control switches. An understanding of this type of control system is crucial to fully appreciate how the savings have been achieved in this case. While most of the specific detail mentioned applies to the case at Land Rover, the information is relevant to the majority of control systems on air compressor plant.



Conventional Control Systems

In the following general description of a conventional control system, it is assumed that there is more than one compressor installed in the compressor house. This case study is not applicable to single compressor control.

Pressure Setting

Usually the lowest acceptable pressure at the compressor house is determined by the minimum pressure needed by the most critical piece of machinery on the network. At Land Rover this minimum pressure is 5.9 bar (86 psi) at the point of use, and if the pressure drops below this value, production is stopped and financial losses are incurred. Hence the lowest pressure acceptable at the compressor house must be able to sustain 5.9 bar at the particular machinery concerned.

For a large compressed air distribution network the line pressure losses to the furthest point on the distribution network may be as high as 0.7 bar (10 psi) at large air demands (pressure losses are proportional to the square of the air velocity). This means that the minimum air pressure must be set at 6.6 bar (96 psi) in the compressor house at Land Rover even though for a large proportion of the time the line losses are less than 0.7 bar. Sustaining this higher pressure has a twofold effect. Firstly the electricity required for compression is increased and secondly the air usage is higher.

The latter situation is further exacerbated when the effect of the compressor control system is taken into account. The typical cascade pressure control system switches compressors 'on load' and 'off load' in incremental pressure steps as shown in the Figure. At the maximum air demand, four compressors operate to maintain the desired end-user air pressure at 5.9 bar. In order to ensure this pressure at the end of the distribution network the minimum pressure in the line at the compressor house was set at 6.6 bar (Stage IV). As the air demand decreases the pressure in the compressor house increases and one of the compressors unloads (Stage III). If the air demand falls further to Stage II, a second air compressor unloads. Provided a run-on timer is installed, the first compressor to unload is switched off altogether, thereby eliminating electricity wastage.

In practice it was found that for most of the time the operating regime at Land Rover was within the Stage II area and at quieter periods, such as lunch-times and tea-breaks, within Stage I. The average pressure in the line within the compressor house was 7.2 bar and by inference the associated pressure at the critical machinery was around 6.6 bar. This represents a 10% excess in pressure at the critical end-use point, leading to greater air usage and higher electricity costs than necessary for compression.

View across the compressor house

In order to overcome these problems two criteria must be satisfied:

- **pressure control must be related to the pressure at the most sensitive/critical pieces of machinery;**
- **the compressor sequence should be based upon as narrow a pressure band as possible in order to achieve the minimum generation pressure.**

Compressor Sequencing

Many compressor control systems have run-on timers so that when the compressor has been idling for a set period it switches off. To protect the motor against overheating from too many start-ups this run-on time is normally set at between 10 and 15 minutes. In some applications this means that compressors are idling for long periods of time unnecessarily. The idling current is typically 40% of full load current which represents about 20% of full load power, leading to substantial energy wastage. This is particularly relevant during break-times. In order to reduce wastage it is essential to **turn the compressor off at the beginning of its unloaded cycle when the cycle is long. This can only be done by predictive sequencing. (See later under Pressure Control).**

Time Control

Time control normally consists of a simple timer that switches the compressors on and off as required. In many applications such as Land Rover's, air is required for 24 hours/day and 7 days/week. However in conventional control systems there is no facility for varying the air pressure setting throughout the time band, hence incurring wastage at times of non-production when generation pressures could be lower. For instance at Land Rover the air is required full time for opening furnace doors, but 5.9 bar is not needed for this operation. In order to optimise the pressures it is essential to **alter the generation pressure to match the site requirements. Critical machinery may not be operating 24 hours/day and lower pressures may be tolerated in certain time bands such as lunch-breaks and Saturday mornings.**

New Compressor Control System

The new control system has been designed to overcome all the drawbacks of a conventional control system described above, as well as giving other benefits. The main features of the system are:

Pressure Control

The generation pressure is regulated in response to a pressure transducer placed at the end of the air distribution network. The system constantly monitors the end-user pressure and adjusts the generation pressure to obtain the optimum within the compressor house. The pressures and pressure band limits can be set at a remote terminal.

The demand is determined by monitoring the rate of change in pressure. Thus the new control system determines whether a machine should be started, when the capacity of compressors running is insufficient, or stopped when the running capacity is too large. By responding to changes in demand it overcomes the need to have set pressures for individual machines, thereby eliminating the total wide pressure control band inherent in cascade control. The pressure can be set to suit the application directly. The range or pressure differential can also be set: too narrow a band will lead to frequent cycling whilst a wide band will incur the penalties of cascade sequencing. Alternatively, especially where the maximum safe range is large, the control system can be set automatically to calculate the most economic range for the load at the time of reaching the top of each pressure cycle.

By observing the rate of change in pressure, the new control system can also predict how long it is likely to be before a compressor is needed again and hence shut the compressor off completely, avoiding idling losses. This is known as **predictive switching**. In practice a time limit still has to be applied to ensure that the compressors do not start more than four times each hour. This is avoided by switching on another available compressor once this limit has been passed.

Time Control

At Land Rover, the new control system has six different time/pressure bands to ensure that the lowest possible generation pressure is achieved at all times. These time periods and pressure bands can be set on a 7-day clock at the remote terminal.

Remote Control

The new control system is provided with a remote control unit based on a computer terminal which enables all pressure settings to be adjusted in the engineers' workshop and allows continuous maintenance surveillance of the compressors. There is also a comprehensive logging facility that records hours run, time on/off load, number of starts, etc for each compressor.

Installation and Commissioning

The new control system was installed with no interruption to production. Most of the hardware was installed while the compressors were running on their existing control system and the link up to the automatic control and commissioning was carried out over a bank holiday weekend. Wiring had to be installed to connect the remote terminal in the engineers' workshop to the compressor house and to the end pressure point sensor. These links were approximately 500 m and 1,100 m respectively.

During commissioning the actual generating capacity of each compressor was measured. This was achieved by attaching a long piece of straight pipe with a calibrated orifice plate to each compressor in turn. The purpose of this calibration exercise was to enable the control system to choose the most efficient compressor. The actual generation capacities of the compressors varied by between 3% and 10% from their design output.

New remote control terminal

No problems were encountered during commissioning and the system was ready for automatic control on the target date.

Since the original manual control system remained in place it eliminated the possibility of lost production if a problem had been encountered. All features of the automatic control system can be overridden to manual control if desired; indeed this happens automatically in the event of a failure of the new control system or of the sensor communication.

Operational Control Settings

The control settings for the new system were tuned over a period of 5-10 weeks. Because of the overriding priority placed on production the engineering staff were understandably cautious about making radical changes in pressure settings.

Initially only two time bands were chosen: weekdays and weekends (excluding Saturday morning). The weekday minimum control setting at the end-user was gradually reduced in 0.07 bar (1 psi) stages from 6.2 bar (90 psi) down to 5.8 bar (84 psi). This corresponded to a compressor house pressure reduction from 6.9 bar (100 psi) to 6.5 bar (94 psi), simply achieved by typing in the new figures at the central control. These pressures compare with a constant 7.2 bar (104 psi) at the compressor house of the original cascade control system (ie a 10% reduction in generating pressure).

The weekend minimum control pressure was gradually reduced down to 5.4 bar, corresponding to a compressor house pressure below 6.2 bar. This compares with a pressure of around 7.2 bar (104 psi) with the conventional control system, ie a 20% reduction in generating pressure.

Further refinements were then introduced by increasing the number of time bands to cater for lunch-times and Friday night/Saturday morning, during which weekend pressure settings of 5.4 bar were used.

Finanical Assessment

The annual direct savings at the time this case study was published were projected to be worth £24,000. (This compares with a pre-installation estimate of £25,000/year).

Indirect savings, through the elimination of leaks, were worth an additional £21,000/year.

The system achieved energy and cost savings as follows:

Weekday — The average reduction in weekday electricity use was from 10,900 kWh to 9,100 kWh, a reduction of 16.5%, equivalent to £360/wk.

Weekend — The average reduction for the whole weekend was from 14,000 kWh to 10,500 kWh, a reduction of 25%, equivalent to £140/wk.

Capital Cost Breakdown

Item	£ Cost
• Controller plus 2 transducers	9,900
• Installation	8,500
• Compressor link units	4,900
• Installation	2,500
• Flow measurement and reporting system	5,400
• Commissioning	500
TOTAL	**31,700**

Potential Users

There are many companies with multiple air compressor installations which could benefit from the sophisticated control offered by the new system. To show significant benefits and a good payback period, installations of three or more compressors are favoured. The compressors need not be in the same location. The control system can be extremely useful in reducing the excess pressure or eliminating hunting conditions that can occur with single compressors located around a ring main system. Under these circumstances remote checks on pressures are made and decisions taken automatically about which machines should be used. A payback period of less than two years should be achieved in most applications.

A breakdown of the £31,700 cost for the supply and installation of the new control system is presented in the Table. Based on direct savings of £24,000/year, the simple payback period is 16 months.

Compressed Air Leakage

The monitoring of compressed air flow rate alerted the engineering personnel to the large offtake outside normal production hours. This represented 0.85 m^3/s (1,800 cfm), approximately 40% of production usage. The production directors concerned quickly remedied the major leaks, resulting in a further electricity saving of £21,000/year.

Thus the savings were almost doubled, and the payback halved, through stopping the compressed air leakage identified by the system.

Other Benefits

Other benefits have been obtained from the automatic control system and remote terminal:

- improved information regarding the maintenance state of the compressors, available at the remote terminal;
- indication of air output rate which can be compared to compressor design figures and used as a performance indicator;
- audible or visual alarm in the engineers' workshop to indicate high or low pressure problems;
- equal sequencing of all compressors thereby ensuring even wear.

In some circumstances de-manning of the compressor house may be feasible with the new control system. At Land Rover, however, two other compressor houses are covered by the same operator so it was not possible to reduce the manning.

Checking the air flow and pressure record chart

Land Rover's Experience

By using an automatic control system for compressed air generation Land Rover cut waste which had occurred in two ways:

- compressed air leaks in the distribution system;
- using more energy than is needed to generate the compressed air.

The former is the subject of an ongoing programme requiring vigilance throughout the factory to reduce leaks. The latter has now been reduced significantly with the Rapaway Air Marshall. In fact, the new control system is proving to be cost-effective. Previously, compressed air was generated inefficiently owing to an inflexible system of pressure switches configured in cascade. This resulted in a high delivery pressure for a large part of the operating cycle as well as compressors idling wastefully off-load for long periods.

The Rapaway system monitors the air pressure at the point of use and controls the generation pressure to just satisfy demand; it also selects the best combination of compressors to meet that demand.

Land Rover, Solihull site

Matching the minimum amount of electrical energy to the actual air demand is the key to energy efficiency.

In addition to the energy saved by generating compressed air more efficiently there are other indirect benefits the system provides, such as identifying when maintenance may be required in the event of compressor performance deterioration.

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Land Rover

Part of the Rover group, Britain's largest motor manufacturer, Land Rover is the world's only major company exclusively building four-wheel drive vehicles. Global export markets account for 70% of the output of the Land Rover factory at Solihull. This site covers about 300 acres, and it is here that the full range of Defender, Discovery and Range Rover models is produced, as well as engines, transmissions and components.

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