An investigation into compressed air wastage at the stopes in underground mines shows that rock drill operators (RDOs) leave manifold valves open due to negligence and for purposes of ventilation.

This habit among RDOs causes a pressure drop at drills and extends the RDOs’ drilling time and results in extended risk exposure, negativity among RDOs and a potential cause for strikes. It creates the need for an intelligent mechanical valve which closes automatically when certain conditions are met.

The authors are involved in developing an automatic air closing valve suited to the mining environment. This valve will close automatically when it experiences excess flow and will open once backpressure is experienced. The impact the valve will have is that of a lower risk working environment, lower use of energy as well as an improved drill supply pressure.

Underground mining relies mainly on compressed air for most of their operations as most mines had compressed air infrastructure installed at a time when electricity was far less expensive than it is today. Apart from the cost factor, it is also much simpler to install air pipes as you advance underground. There is also no need for equipment to expel the air once used underground.

On average, compressed air consumes 15% of mines’ electricity bills. Fig. 1 shows the average consumption in the mining industry. There are, however, mines where compressed air consumes up to 50% of total power.

When breaking up the compressed air users on a mine, it becomes clear that the largest consumers are leaks, wastage and loss. Other main consumers are rock drills, load box pneumatic cylinders on the surface and underground, dirty water and mud dam agitation, and refuge chambers. Most air-operated equipment can be replaced with hydro powered or electrical technology.

Although conversion from compressed air to hydro-powered operation means a significant increase in efficiency, this conversion is costly and not implemented widely. Where this has been implemented, it was done over a long period. The compressors can only be switched off once the last compressed-air user is converted. This opens up an avenue for optimising current compressed-air reticulation networks and technology.

Leak detection surveys were conducted at various gold and platinum mines and these have shown that the majority of compressed-air wastage occurs at the stopes. It is fairly accurate to say that this inefficiency at the stopes is one of the main contributors to the base load of the compressor power demand curve shown in Fig. 2.

![Fig. 1: Average mine process electricity consumption. [1]]
In this case, the base load consists of up to 90% of the energy consumed during a normal weekday. Only 10% of the energy is used for air operated drilling, which is directly linked to the tonnage produced. Therefore, the technology referred to in this article focuses on compressed-air wastage at the stopes. This area is considered the most difficult working place in underground mining. RDOs do not necessarily have an interest in saving energy or in compressed-air wastage. Their performance is measured purely on the tonnes of ore they break. It was found that RDOs leave thrust legs or manifold valves open due to negligence and for ventilation purposes. It was established that this habit also causes a pressure drop at drills. The drop in pressure results in an increase in drilling time which, in turn, results in:

- Extended risk exposure in a very dangerous working place.
- Negativity among RDOs as they must meet their production targets with very low air supply pressure, meaning that they must physically work harder and longer.
- Lower air pressure means longer drilling penetration rates and reduced production and lower production bonuses. These bonuses often make up a large part of their annual package.

Fig. 3 shows clearly the advantages of increased drilling supply air-pressure. It can result in fewer drills and RDOs needed to accomplish the same, or even higher, production rate.

**Impact**

To narrow down the effect and to make it more tangible, the focus was on the effect of a single air valve of defined size, left open. The valve used on this branch is a 25 mm diameter manual ball valve (see Fig. 4). The effect is double-sided: it has an energy cost implication as well as a reduced pressure drop at the drill, causing a lower drilling penetration rate.

**Cost implication**

It is necessary to establish how much energy is required to generate a certain amount of compressed air, as well as the leak volume flow rate to calculate the cost of compressed air in basic terms. With compressor energy and volume flow rate data available, it is possible to quantify the energy needed to generate a volume of compressed air at normal conditions. This amounts to 6.6 Nm³/h per kW at the elevation where the mines are situated. This compares very well with actual measurements.

The Moss equation is used to quantify air flow rates through an orifice. Each type of orifice has a different coefficient of flow. The typical punch-hole leak experienced underground was measured with an air flow meter to obtain the most suitable calibrated coefficient of flow:

\[
W = 0.5303 \frac{AC_{f1}}{T_1}
\]

where:

- \(W\) = discharge in lbs. per sec.
- \(A\) = area of orifice in square inches.
- \(C\) = coefficient of flow.
- \(P_1\) = upstream total pressure in pound per square inch absolute.
- \(T_1\) = Upstream temperature in °F.

The calculated cost based on Eskom’s 2013 Megaflex tariff for a 25 mm opening at 350 kPa is R43 950 per month. Posters at the mine aimed at making employees aware of this expense indicate that a 25,4 mm leak under a 480 kPa pressure costs their operation R57 000 per month.

**Lower drilling pressure in perspective**

Drilling times increase significantly with a decrease in drill supply pressure. A Flownex CFD simulation was done to determine the effect one open valve has on the reticulation network on one level. It indicated a significant difference in the effect, depending on the position of the open valve. Open valve closers to the station have a bigger effect downstream than when opened at the furthest point.

One valve opened to atmosphere closer to the station can cause a pressure drop of 50 kPa. The effect of this pressure drop depends on the potential pressure in the working area. This calculation is based on a measured station pressure of 450 kPa.
364 kPa after friction losses were accounted for. With the 25 mm valve open to atmosphere, it decreases the pressure to 314 kPa.

The time it takes an operator to drill a 1200 mm hole with a pneumatic drill at 364 kPa is 341 sec. With the 50 kPa pressure drop, it takes the operator 431 sec. The 90 sec. increase on one hole becomes just more than an hour per RDO in one shift when 130 holes must be drilled.

It is therefore apparent that a relatively small change in drilling pressure has a large effect on drilling time and, proportionally, on production.

The need
A need therefore exists to prevent thrust leg valves from being left open. The effect is significant and must be countered by a robust and easy-to-use solution.

A possible solution would be an intelligent mechanical valve which closes automatically when certain conditions are met. This valve has to open and close automatically during both drilling and no-drilling periods.

There is currently no valve available in the industry which meets the full required design specification or which suits the industry and environment it must operate in. This has prompted the authors to specify certain requirements and to design such a valve.

Valve design specification
A few important aspects must be borne in mind when specifying new technology for underground mining:

- The technology can never have a negative effect on production performance. It must therefore be in a safe position or have a safe effect when it fails.
- Added to this, it cannot have a negative impact on the working experience underground. It must be very easy to operate. Once there is a negative perception about the valve, it will almost certainly be damaged.
- The valve must also be robust for the very humid, dusty and hot underground conditions.

The valve must be tamper-proof.

Required technical specification
The design requirements shown in Table 1 were determined by carefully studying equipment operating in a similar environment.

Should the required specification not be met, the automatic air closing valve will not stand up to the environment it is intended to work in.

Valve design, operation
Valve conceptual design
Opening and closing operations should be considered during the design of the valve. The valve must provide an improvement to working conditions to prevent vandalism. The forces involved in opening and automatic closing of the valve are shown in Fig. 6 and consist of the valve body, plunger or closing device, and a coil spring.

There are three major forces working in on the plunger. When the sum of the downstream pressure force \( F_{P2} \) and the coil force \( F_{COIL} \) is bigger than the upstream pressure force \( F_{P1} \), the plunger will be pushed back and the valve is in the open position.

Should the flow increase and the backpressure be reduced to cause a pressure drop over the plunger, the plunger will retract and close the valve as the upstream pressure force \( F_{P1} \) becomes higher than the sum of the downstream pressure force \( F_{P2} \) and the coil force \( F_{COIL} \).

Operation: start-up sequence
At present, the RDO will connect his drill to the 25 mm ball valve and open it. The 25 mm line is then under pressure and the flow is controlled by activating a valve on the drill.

When the automatic air closing valve is installed, the RDO must turn an automatic return knob to charge-up the line. The knob will open an internal bypass of 5 mm in the valve which will allow flow through to equalise the upstream and downstream pressures of the valve. Once the downstream pressure equalises the upstream pressure, the main valve will open and the activation knob will return to close the bypass port.

Operation: closing sequence
The current closing operation expects the RDO to close his drill trigger valve and to walk to the thrust leg to close the 25 mm ball valve. He then walks to his drill to disconnect the line and his shift is completed.

With the automatic air closing valve installed, the RDO will only have to close his drill trigger valve and disconnect the line. This is where additional improvements and savings are achieved. The valve will sense burst pipe conditions and close immediately.
For the remainder of the day, the valve will be closed and only open once a drill is connected to it.

Valve manufacturing
The authors have developed the valve to the specifications mentioned here (see Fig. 7). It is currently undergoing testing and once all the test requirements are met, will be manufactured and installed in mines where air drills are used.

Theoretical impact
The idea is to replace the existing 25 mm ball valve with the automatic air closing valve on the mines. In addition, training will be provided to mine captains so that they can train the RDOs.

Typical mine layout
The mine used in this example is a typical underground platinum mine, with an average monthly production of 150 000 tonnes of hoisted reef and waste. It consists of nine working levels with 20 half levels. The number of drills used is broken up as follows:
- Production crews – 49
- Re-development crews – 48
- Development crews – 14
- In-stopes crews – 4

The mine has 115 thrust legs and 690 ball valve openings in total.

Calculations based on underground survey
A survey was done to quantify the effect on energy usage when a number of 25 mm thrust leg valves were left open. The aim was to obtain a general idea of how many valves were left open per thrust leg.

The survey was done on various stopes of various mines and it was found that more than 5% of the valves on thrust legs are left open or damaged and cannot close. This number differs from mine to mine and can be directly related to the discipline on that mine.

The cost and payback calculations are based on Eskom’s current MegaFlex tariff. The total energy wastage cost per month for this mine amounts to some R1,5-million.

The total cost to install automatic valves on all thrust leg branches as they are supplied to the mine is approximately R1 518 000. This means that the cost of installing the automatic air closing valve can be recovered within four weeks.

This payback is financially very attractive and the effect of the increase in drill pressure on the rate of production has not even been taken into consideration.

An additional safety aspect
Injury risk mitigating is a major focus in underground mining. Injuries occurred where the air pipe connected to the drill came loose due either to insufficient clamping or breakage of the line. This could cause severe injuries as the line is under pressure.

The automatic air closing valve will eliminate this risk as it will close as soon as the pipe is disconnected. There will not be sufficient pressure in the line to cause any injury.

Conclusion
Compressed-air is an expensive commodity on underground mines. Poorly disciplined working environments cause already inefficient compressed-air systems to be even more inefficient. This created an opportunity for energy saving and optimisation of compressed-air use. Feasibility research on installation of the technology discussed in this article shows that there is potential in the market to roll the new technology out to all underground mines using compressed-air for drilling.

The effect is two-sided: it not only reduces compressed air wastage, but also increases production by increasing drill supply pressure.

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References

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Fig. 5: Thrust leg used for drill connects to in-stopes supply.

Fig. 6: Automatic air closing valve illustration in design phase.