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Use of intensive remote monitoring and artificial intelligence to optimise paste pump availability on paste fill

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Abstract

It is widely recognised that a conventional paste fill plant layout incorporates several pieces of equipment used to build and dispose of cemented paste in the underground mine. From all the related main equipment considered in a conventional paste plant, the pumping system plays a key and crucial role for paste pouring underground on a safe and controlled way through a high-quality paste that needs to meet the unconfined compressive strength (UCS) required underground based on the design to meet the mining cycle.

This paper as a continuation of a previous paper presented by Gamboa & Castilla in 2024, aims to analyse and study how continuous monitoring of a piston-diaphragm type pump and the usage of artificial intelligence (AI) applied to the vast amount of data collected, has enabled the entire paste plant to achieve availabilities above 97% by substituting conventional preventive or corrective maintenance practices with a predictive procedure. Exploiting the data collected by the pumping system applied to paste fill will provide a good opportunity to create intelligent systems in the near future, as some works have been done already with a similar principle to predict UCS underground (Mariem et al. 2024).

This system offers clear benefits on the pump and therefore paste plant availability and reliability, while enabling a smooth maintenance and paste production planning, with an optimum binder dosage and mining cycle synchronisation.

Keywords: *paste pump, paste fill monitoring, artificial intelligence*

1 Introduction

Positive displacement pumps (PD Pumps) usage is commonly established in paste plants all over the world. This type of pumping technology is the most adequate to handle high-density and high-viscosity pastes, which make the pumping requirement feasible thanks to their operating principle. However, paste transportation is a complex task which demands a detailed engineering and design of the equipment selected. Until the date this paper is written, the usage of hydraulically driven piston pumps has been the common practice in the paste fill industry, however the usage of piston-diaphragm pumps has ultimately disrupted with this design in the last few years (Correia & Jacobs 2024). The utilisation of PD pumps is widely established in paste plants globally. This pumping technology is particularly suited to handling high-density and high-viscosity pastes, rendering the pumping requirements feasible due to their operating principles. However, paste transportation is a complex task that necessitates detailed engineering and design of the selected equipment.

Typically, in the paste fill industry high-density paste recipes are prepared which, depending on the pipe diameter selected as per the hydraulic model lead to different paste velocities inside of the reticulation system, this circumstances demand distribution systems and pumps ready to operate in pressure losses values in the range 5–12 kPa/m.

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The pumping system plays a crucial role for transport and paste disposal underground (Febritirtana et al. 2024), thus it is mandatory to consider a reliable and available pumping system capable of continuously working with such a complex material to be pumped. Both operation and adequate maintenance of these type of pumping systems are required to achieve the maximum availability of the system, which has a positive direct impact on the paste plant operation on surface; and underground, on the cold joints mitigation on the stopes and the mining sequence.

Generally, the pumping requirement in these installations vary on a range of 50–200 m^3/h; and discharge pressures up to 15 MPa based on the previous pressure losses described and the distance to be covered. To meet these requirements, piston-diaphragm pump technology manufactured by ABEL sizes vary from 120 m^3 up 160 m^3 in volume, while same pumps weight between 28–60 t as the two examples given in the Figure 1.

Figure 1 Medium size piston-diaphragm pumps examples in cemented paste fill plants

2 Piston-diaphragm pumps description

This type of PD pumps consists of an electric motor, which is coupled to an intermediate gear through its input shaft and coupled to the main gearbox through its output shaft. Main gearbox can be designed as per a crankshaft design or a pinion-wheel design if 2 or 3 pistons are required for the design, it transforms the rotative moment of the items described into a linear and alternative movement through the eccentric rods. These eccentric rods are bolted to the pump pistons through the piston rods. With the movement of the pistons a hydraulic propelling liquid is delivered through the compression housing to the pre-shaped diaphragms which are displaced in consequence, the diaphragm is the part which is in contact with the cemented paste and delivers the product out of the pump thanks to the suction and discharge non-return valves which ensure the suction and discharge stroke volume flowing though the wet side of the pump. Additionally to this principle which demands and alternative flow, both suction and discharge dampeners are included in the pump respective manifolds to ensure a smooth and continuous flow with limited pulsation in the suction and discharge paste pipelines. The right selection of these items is important to ensure a smooth and safe operation described in detail by Correia & Jacobs (2024).

Figure 2 represents the cross-section of this pump in accordance with the principle described. Based on this ABEL differs and divides the pump in three different sides which are significantly different in the maintenance tasks and frequency to be performed during pump lifetime:

- drive side
- hydraulic side
- paste side.

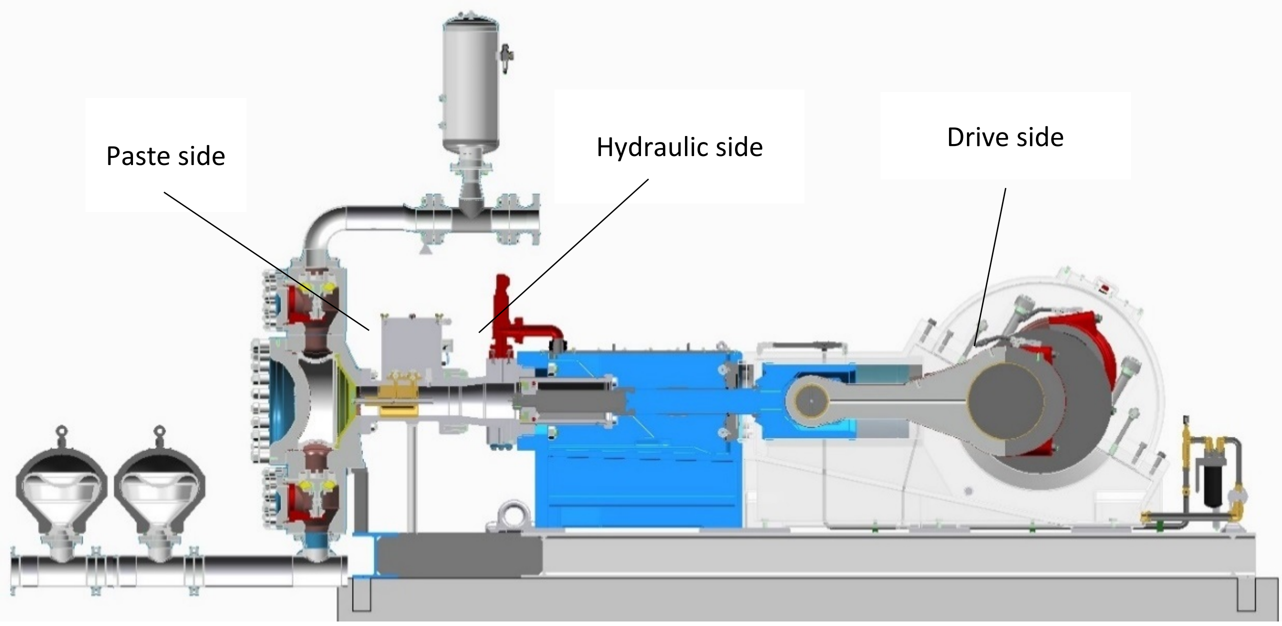

Figure 2 Piston-diaphragm pump cross-section (without motor)

As per the design, this is a heavy duty and high efficiency pumping system, however downtime and maintenance tasks required have been considerably improved and optimised thanks to a remote monitoring system developed by ABEL that has allowed to transform the preventive or corrective maintenance into a predictive maintenance, where the system is capable to read in real-time the 4-diaphragm, two duplex double action piston pump performance and transform it from the information perspective into four individualised single acting pumps working separately. This has been accomplished through an intensive sensitisation initiative within this pumping technology.

3 Pump failures and maintenance

It is evident that all those parts in direct contact with the fine and abrasive cemented pastes are facing wear, therefore those are the most frequent and critical parts to fail and be maintained, consequently the paste side will be the most frequent side of the pump to be inspected.

In the paste fill industry, there is a widely spread common practice which consists of programming a preventive maintenance task on the paste pump every week, or every second week, or alternatively after the stope backfill process completed. This policy is different depending on how the preventive maintenance is approached in every mine site, the utilisation ratio of the paste plant and pump; or the availability and reliability of the piece of equipment used in a particular paste plant operation.

In the case of a piston-diaphragm pump, the routine tasks to be performed include the inspection of the valves and seats (four in suction and four in discharge), the housing and condition of the diaphragms; and, much less frequently, the hydraulic side of the pump. All these tasks can be completed within 24–48 hours by the maintenance team, depending on the experience and skill of the personnel performing the task.

In the event of a loss of efficiency caused by the presence of a foreign oversized particle in the paste recipe, the task to be performed is to stop the pump and carry out an inspection. In these situations, it is necessary to open the valve block in the case of a hydraulic piston pump, whereas it is necessary to open the check valves one by one in the case of a piston-diaphragm pump.

In this regard, the probability of the maintenance team identifying the fault on the first attempt is between 8–16%, while it may be necessary to open all the valves if the blocked or damaged component is not identified initially. This process can extend up to 2 hours just for valve opening.

In Table 1, the maintenance times caused by normal wear and by wear due to an external element to the paste recipe are shown for a medium-sized pump used for cemented paste fill:

Table 1 Mean time between failures and mean time to repair (Gamboa & Castilla 2024)

Parameter	Value (hours)
Mean time between failures (wear)	>4,000 h
Mean time between failures (foreign material)	>500 h
Mean time to repair (wear)	0.0833 h (flushing) + 0.33 h (repair)
Mean time to repair (foreign material)	0.0833 h (flushing) + 1 h (repair)
Mean time to repair (without ABEL SPA)	**1 h (flushing) + 4 h (repair)**

4 Monitoring system

This monitoring system has been developed in collaboration with the supplier with the aim of equipping ABEL PD pumps, dedicated to tailings management in general and mine backfill in particular, with a more robust and reliable system that minimises maintenance and increases availability.

It is common practice in mine backfill operations to have one pump in operation and another on standby due to the critical nature of cement backfilling. However, not all installations worldwide have a redundant pump, primarily due to the high initial investment required for these pumping systems.

Regardless of the approach, it is commonly established in the industry to schedule maintenance shutdowns for the pumping equipment once a stope has been completely backfilled, or to perform this task after one or two weeks of continuous operation. This is done to avoid unexpected long-term failures caused by premature breakdowns resulting from the lack of preventive inspection of certain components (especially those in contact with the paste).

To breakaway from this maintenance policy in the mine backfill industry, an integration has been with a monitoring system into the piston-diaphragm PD pumps. This system allows the user to avoid opening the pump for inspection, thanks to the extensive set of information that is constantly collected through this system.

This system allows for the assessment of the condition and wear of each component, whether it belongs to the side in contact with the paste, the hydraulic side, or the drive side. Consequently, it significantly reduces the number of maintenance tasks to be performed and enables the user to precisely identify the point of the pump to be inspected. In other words, a routine preventive maintenance task that might take 24 hours of work after backfilling a specific stope can be reduced to a maintenance task of less than 3 hours as the maintenance team is headed by the data gathered to the exact component which is slightly or severely damaged. This means the system becomes available again very quickly and does not become the critical element or bottleneck for operational continuity. Additionally, this system offers the possibility of not considering a pump as a reserve in circumstances where it was previously unthinkable.

4.1 Monitoring system description

The monitoring system is divided into two groups of signals:

- Safety signals: these are all the safety signals that monitor the equipment and protect it from excessive temperature, pressure, and diaphragm rupture signals. They are permissive interlocks for the operation or non-operation of the pump.
- Operational tracking signals: these signals divide the pumping set into individual operations of each housing from an informational point of view. These include displacement sensors and pressure sensors.

In Figure 3, user interface of this system can be seen where the safety signals of the pump are displayed in the lower graph, while the two upper graphs show the individualised signals of each pump housing performance. The example graph shows a duplex double-acting pump with four diaphragm sides.

Figure 3 Monitoring system user interface

4.2 Monitoring system data collection

All the information collected by this system is sent to a Gateway, which automatically transmits the data to the cloud every 3 minutes. Under certain circumstances, the user can send a PIN to the system to collect data at any time outside the automatic intervals that the system performs autonomously. The volume of data provided is such that it is not feasible to perform automatic data collection more frequently with this system.

All this information is transmitted over the internet via a wired connection or through a SIM card included in the solution offered. Once this information is uploaded, the user can view all the data on a computer, tablet, or smartphone from anywhere in the world. This allows operators, fitters, supervisors and even ABEL service engineers to provide their input and make the best decision to the paste plant operation.

4.3 Artificial intelligencepowered data analytics and action recommendation

To provide the best possible support to the operations and maintenance team at the backfill plant, an AI solution has been developed which enables worldwide, round-the-clock service. The AI analyses incoming data every three minutes continuously, providing automated failure diagnosis and action instructions via a mobile app, and stratify this communication in different levels for actions to be taken between fitter, supervisor or backfill manager. The AI can distinguish between event-based failures, which need immediate resolution and typically occur without any pre-indications, and wear-based failures, which follow a degrading trend and allow for the prediction of the remaining operational time before the corresponding part needs replacement. Figures 4 and 5 illustrate examples of these failures and demonstrate how communication with the onsite team is facilitated via the mobile application.

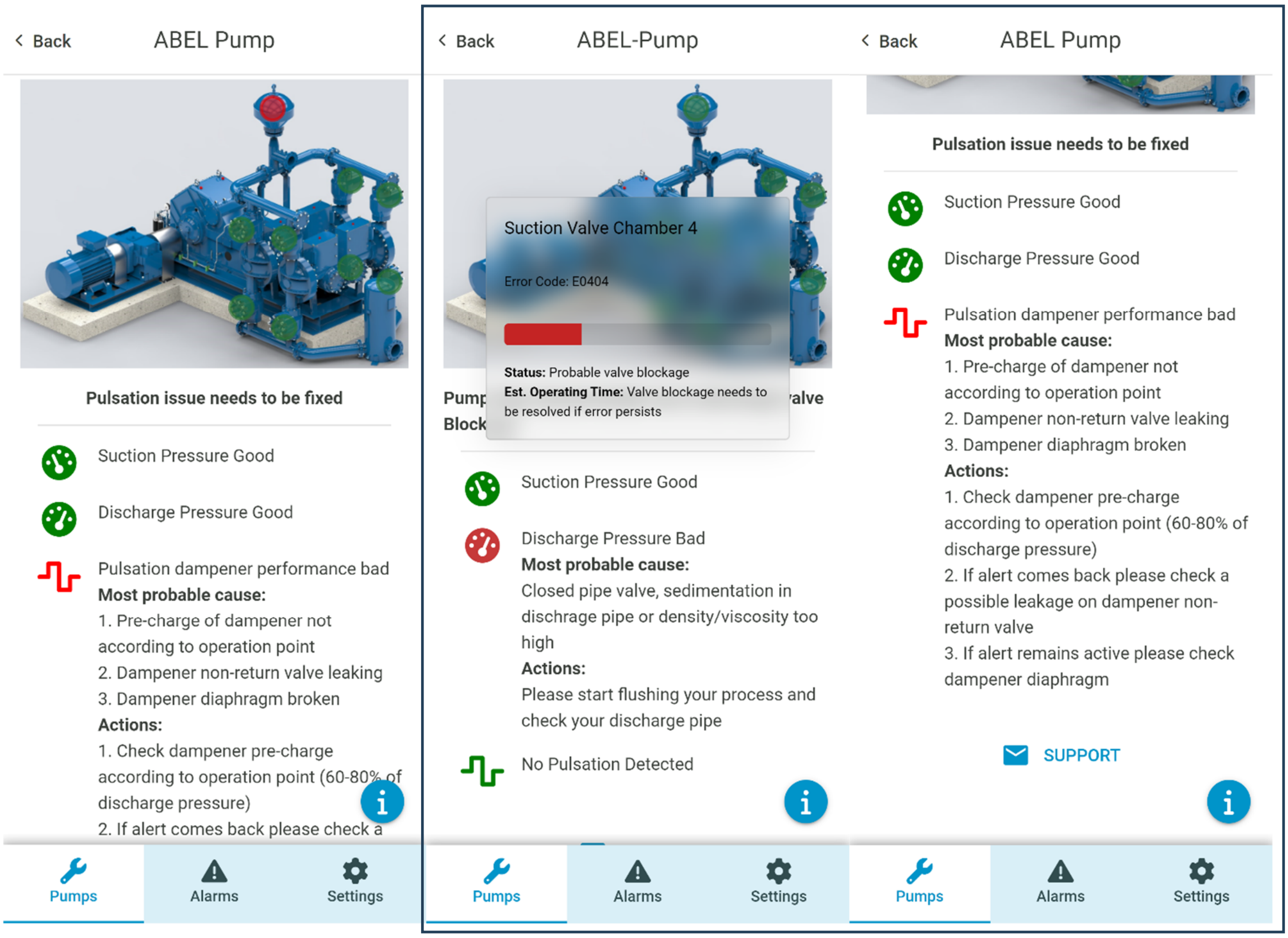

Figure 4 Action instruction and failure diagnostic

The action instructions assist the maintenance and operation teams in making quick decisions. Figure 4 illustrates a real case where the pump experiences a suction valve blockage in chamber 4, caused by particles that exceeded the paste recipe specification. This scenario exemplifies an event-based failure that requires immediate resolution, as it can lead to subsequent issues such as diaphragm rupture which would subsequently demand a longer downtime of the pumping system and cost to repair. Additionally, Table 2 lists failures that the AI has already been trained to recognise and address, representing the most common failures encountered during the operation of PD pumps in paste backfill applications.

Table 2 Failures capable to identify by artificial intelligence system

Wear-based failure	Event-based failure
Discharge valve wear	Suction pressure too low
Suction valve wear	Discharge pipe blockage
Sedimentation suction pipe	Pulsation dampener performance bad
Sedimentation discharge pipe	Suction valve blockage
	Discharge valve blockage
	Hydraulic control functionality

The semi-supervised learning model is currently leveraging over 40,000 data sets of real cases to enhance its learning capabilities. In addition to this substantial amount of real data, it has been generating a vast array of artificial data derived from these real cases. This approach strengthens the AI by creating a higher number of variations. It is continuously labelling real cases from customer feedback, ensuring an ongoing process of data enrichment. It is crucial to have a diverse range of 'okay' labels from different operation points and rheology/paste recipes which are not always exactly the same in a paste plant operation as it is worldwide known. This diversity ensures that the AI comprehends a broad spectrum of operational performances exhibited by PD pumps. By incorporating this extensive and varied data, the AI becomes increasingly robust, capable of functioning across a variety of applications and operational challenges without compromising the health of the pumps.

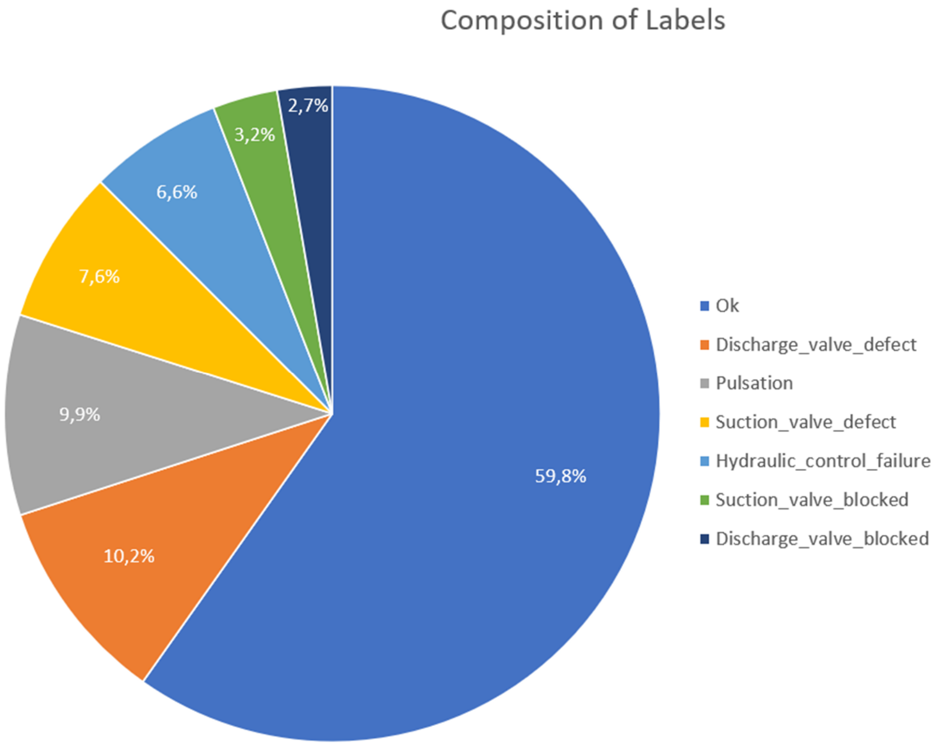

Figure 5 Distribution of failure pattern labels from real cases

In Figure 6, a plot is displayed that is primarily used to monitor the progress during the training phase of the model. One of the key metrics shown is the validation loss, which represents the error the autoencoder makes when attempting to reconstruct a set of test data. As the model improves, this error should decrease, indicating that the model is becoming more proficient at accurately reconstructing the given plots and data. This value is assessed after each training cycle, meaning after each epoch in which the model has processed the entire dataset for training. Currently, there are a conducts of 60 such epochs for the autoencoder, so the x-axis of the plot ranges from 0 to 60.

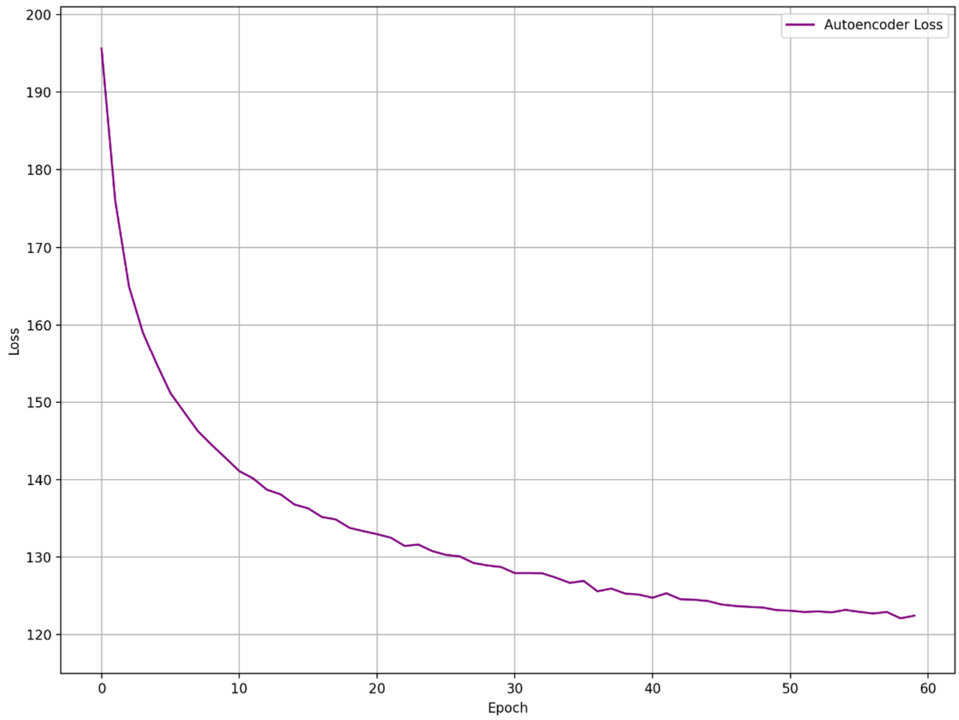

Figure 6 Validation loss of model

Another crucial parameter for evaluating the classifier's performance is accuracy. This metric reflects the proportion of correctly classified samples from a set of test data, as depicted in Figure 7 Ideally, this accuracy should increase as the model's performance improves. In this specific case, the system is achieving an exceptional high accuracy, approaching a value of 1, after just 20 epochs. This theoretically suggests that the task of reconstructing the failure is currently too easy for the model developed. In other words: the model is capable to examine much more complex data. This is visible in the Figure 7.

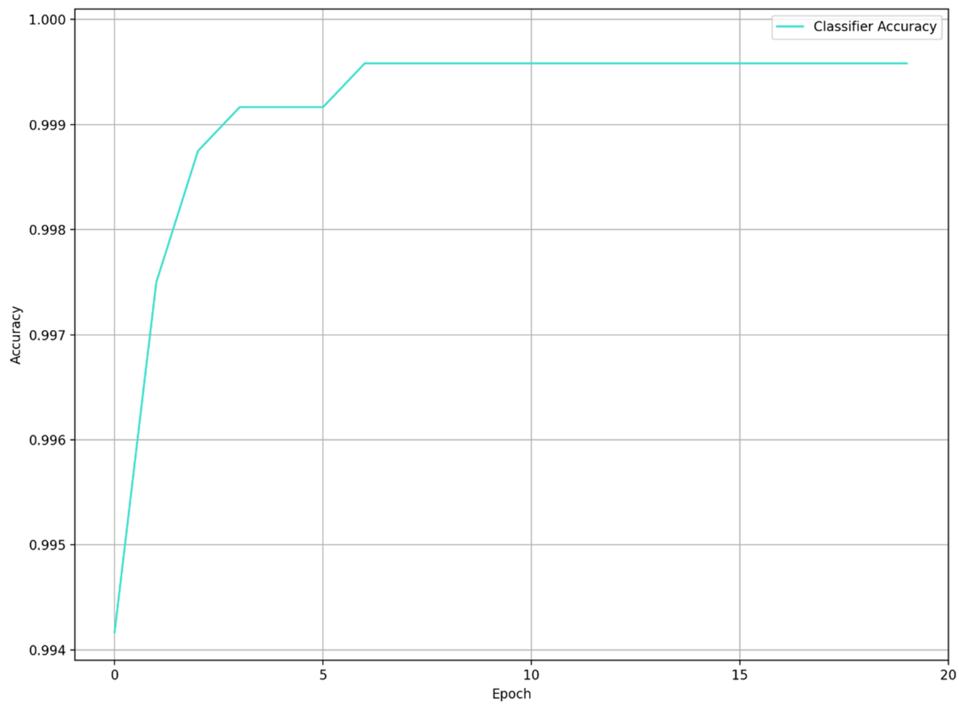

Figure 7 Performance accuracy of model

The classifier processes each dataset and assigns it to a pre-trained label. The output of the classifier is a probability indicating how similar the current data is to an already trained and labelled data, as shown in Figure 5. This is demonstrated by a real case with optimal conditions in Figure 8. The example features a PD pump with a performance of 130 m³/h at a maximum discharge pressure of 60 bar. The density ranges from 2 to 2.4 kg/dm³ on a typical 30–60 mm Boger cylinder slump.

Figure 8 Positive displacement pump in good operation classified by artificial intelligence model

In the meantime, Figure 9 shows a real case of an identification of a suction valve blockage caused by a massive particle size caused by the moisture content in the dry binder dosing system on the connection to the paste mixer which generated an accumulated bulk material at the final section of the screw feeder.

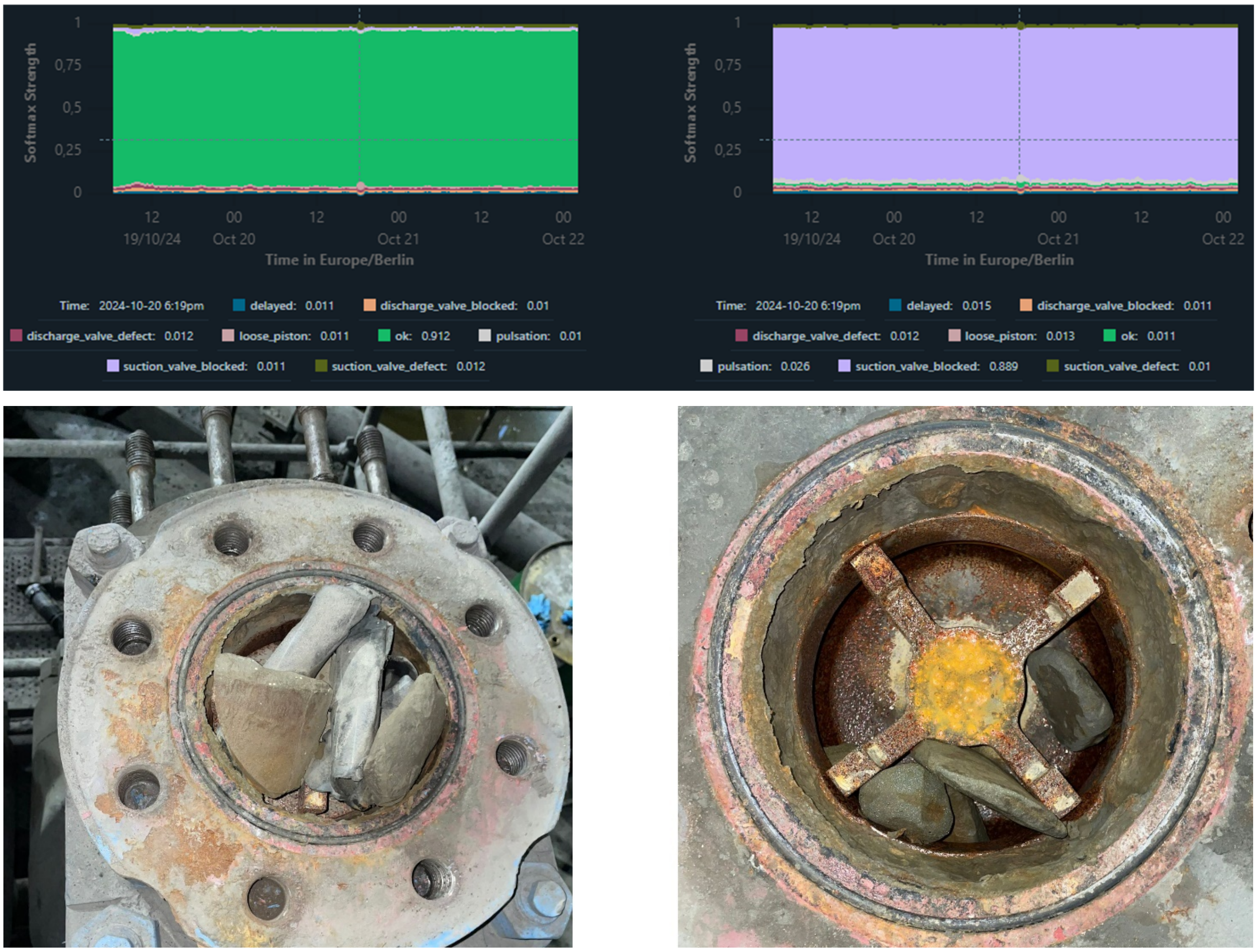

Figure 9 Positive displacement pump operation with suction valve blockage classified by artificial intelligence model

4.3.1 Prediction of wear-based failure

In addition to real-time automatic pump diagnostics, a significant feature of the system is its ability to predict wear-based failures. When the AI detects wear, it activates algorithms to calculate the remaining operational time until the performance of the worn component reaches a critical threshold. At this point, the efficiency of one or more chambers is compromised, nearing the limit of safe operation. This ensures that ABEL can guarantee the health of other components is not adversely affected by the wear. This period defines how long the process can continue to operate with the PD pump. The remaining operational time is influenced by the quality of the paste being pumped while the presence of larger particles in the paste could shorten this time. The system has successfully predicted wear-based failures up to 21 days in advance, which exceeds the typical time required to backfill the volume of stopes in several paste fill operations in the world considering this anomaly is detected at the beginning of the stope being poured out. This capability allows operators to maintain precise and continuous control over the complete volume of the stope while the pump is in operation. The prediction tool employs a predictive indicator and load collective approach. When the classifier identifies a dataset indicative of wear-based failure, the predictive indicator begins to rise.

In cases of typical wear due to abrasion from a paste with a high concentration of fines, the increase in the indicator is gradual and continuous, as showed in Figure 910. Conversely, wear caused by foreign materials not included in the paste recipe results in a steep, almost vertical rise in the indicator, having an immediate impact on the system.

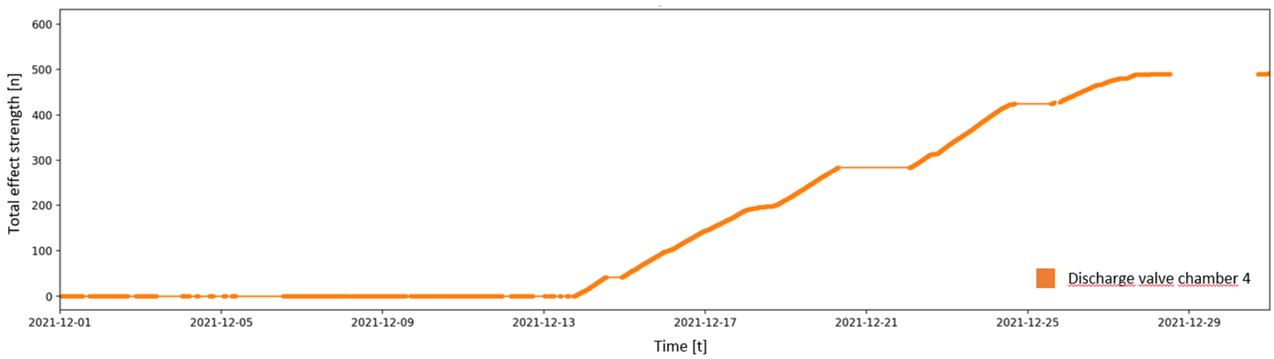

Figure 10 Load collective increases as an indicator of wear and its intensity

The load collective consistently increases whenever the classifying model identifies a failure pattern indicative of wear. The rate at which the load collective rises is determined by a parameter known as effect strength. This parameter acts as a multiplier, combining the identified failure pattern with the assessed strength of the individual effect during the operation of the paste pump. This process also accounts for the degradation in efficiency of the wear part.

The algorithm calculates the remaining operational time until the load collective reaches its maximum threshold, which corresponds to the maximum allowable efficiency loss permitted to avoid impacting other components of the pump. The point at which the load collective is reset occurs when the maintenance team replaces the corresponding worn part.

5 Conclusion

The following conclusions can be drawn from the different sections of the article:

- PD pump has a crucial role on the paste plant operation and availability.
- PD pump is a substantial machine and its maintenance reduction tasks and downtime is critical for a successful paste fill operation and availability.
- Piston-diaphragm pump evolution powered with AI diagnose has enabled to reduce downtime, as prior to a failure system defines the situation and actions to be taken.

- System is capable of predicting failures/wear external to PD pump operation which enable paste fill operators to improve the complete system QA/QC.
- Predictive modelling enables paste fill planning and mitigates the risk of system shutdown while pouring with 21 days in advance for wear-based failures.

Acknowledgement

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