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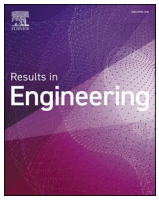

Predictive maintenance on ball mill liner using 3D scanner and its analysis in the mining industry of Papua Indonesia

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ABSTRACT

In the mining industry, the primary production process entails transforming large ore deposits into valuable concentrates. To get minerals from large ores, a grinding machine is needed to reduce the size of the ore, and then the minerals can be extracted. The ball mill is an important part of the grinder in the mining industry. Maintenance is required for the machine to continue to work effectively and optimally. One method of preventing ball mill failures and minimizing company losses on a large scale is to predict the life of ball mill liners or predictive maintenance. Using a 3D laser scan, it is possible to determine the ball mill liner's wear and tear. On the basis of liner wear analysis, this information can then be used to generate a liner replacement schedule or estimate the remaining life of the ball mill liner or relining and lifetime forecast. This study aims to compare the 3D laser scan method and ultrasonic testing method in terms of liner wear analysis and forecasting. This study also demonstrates that the laser scanning method will be more effective and efficient than ultrasonic testing.

1. Introduction

Maintenance is essential to preserving the performance of a machine so that it can continue to operate effectively [1,2]. Maintenance has many positive effects, such as knowing the limits of a machine's usage and maintaining the production process of an industry, particularly in the mining industry. Therefore, an effective and efficient maintenance method is needed to achieve a machine's maximum potential. One of the world's largest mining companies in Indonesia is applied as the primary production process involves converting raw material from large ore into a concentrate containing gold, copper, and silver. Blasting, transportation, crushing, grinding, separation, and the extraction of ore mineral content that is ready to sell are just a few of the processes that occur to convert ore into a concentrate. The purpose of concentrating area is to reduce large stones to the size of fine sand in order to release grains containing gold and copper. The processes in the concentrating area are crushing, milling, floating, and drying. The crushing and grinding process is carried out through two primary machines, SAG (Semi-Autogenous Grinding) and ball mill. The SAG Mill is to reduce the size of the big ore into small size. On the other hand, ball mill converts small ore into more refined grains. After leaving the SAG mill, the ore goes through a screening process before proceeding to the ball mill. A ball mill is essential in the mining process to grind the small ore to fine sand. To grind the ore, the ore collides with the iron ball inside the ball mill. If this collision continues, the ball mill walls will be damaged. Therefore, an inner lining plate or liner that coats the main shell and feeds embedded in the ball mill to prevent damage during grinding that can cause leakage. If the liner is not inspected and eventually wears out, the company will incur production losses because it will have to purchase a new engine. To prevent this from occurring, it is necessary to predict effective and efficient maintenance and to determine the remaining life of the liner.

Grinding is an ore size reduction or comminution operation. The ore is reduced in size to the size of the separator at this point. Impact, compression, attrition/abrasion, and shear forces all play a role in the reduction mechanism. There are numerous types of grinding instruments, such as the rod mill, which employs a cylindrical rod-shaped media that is about the same length as the mill. The grinding process in ball mills involves the use of steel balls as the grinding medium, and the mill is typically designed with a length (L) that is substantially greater than its diameter (D), meaning $L > D$. The length of a ball mill is usually 1.5–2.5 times its diameter. On the other hand, Pebble mills use very hard

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Table 1
Data of ball mill on inspection date.

ML-8	for Shell Liners and Head Liners (FE and DE)
Installed date	Dec 19, 2021
Inspection date	June 23, 2022
Remove date	under operation
Calendar days (Day)	186
Operating hours (Hour)	4344.86
ML-8 Cummulative power (GWh)	8.59
Cummulative tonnage (Count)	1,690,648.00

rock as the grinding medium, and these mills have a long length that is nearly the same as the mill diameter. In autogenous mills, the grinding media consists of the ore itself, and the mill's long dimension is less than its diameter, L < D. Grinding is carried out on mine ore or ore from the first stage of crushing. In case of tube mills, steel balls are used as the grinding medium, and the mill's long dimension is often much greater than its diameter, L > D. The tube mill is divided into various sections on the inside, and it can have two, three, or even four compartments. It should be noted that the ball mill is a type of grinding tool with dimensions of length and diameter that are relatively similar [1,2].

Inside the ball mill, there are iron balls that help the grinding process. The ball mill is divided into three major sections: feed, discharge, and shell/cylinder. The feed section is where the material enters the ball mill, the shell section is the part that covers the ball mill itself, also known as the "body" of the ball mill, and the discharger section is where the material exits.

The inner lining plate or liner, also known as the coating plate, is one of the components in the ball mill that prevents damage to the ball mill wall. The constant rotation and collisions in the ball mill will result in wear and tear on the ball mill walls. Thus, the liner function prevents this from happening. The areas of the liners that receive wear from grinding balls and iron ore particles are the grinding zone and the fracture zone. Furthermore, a slurry is produced during the milling process when wet milling is used. The production of powder or slurry leads to problematic wear conditions. In addition, the worn liners alter the kinetic properties of the aggregate and the grinding balls, which greatly lowers the milling efficiency [3]. This will ultimately cost the company money in terms of production and manpower. Feed, discharge, and shell all have their own liners [4,5]. A typical liner consists of a plate and a lifter. The plate is part of the liner and has a lower height than the lifter because the lifter's function is to lift the iron ball in the ball mill, creating a force on the ball that destroys the material in it.

Non-destructive testing is a technique used to inspect a material's integrity for external or internal flaws or metallurgical conditions without jeopardizing the material's viability for use or destroying it in any way. NDT stands for non-destructive testing, which is the assessment, evaluation, and monitoring process of components and materials

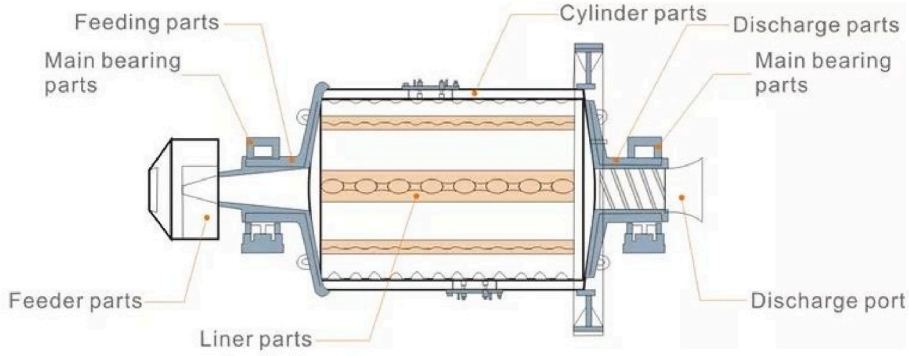
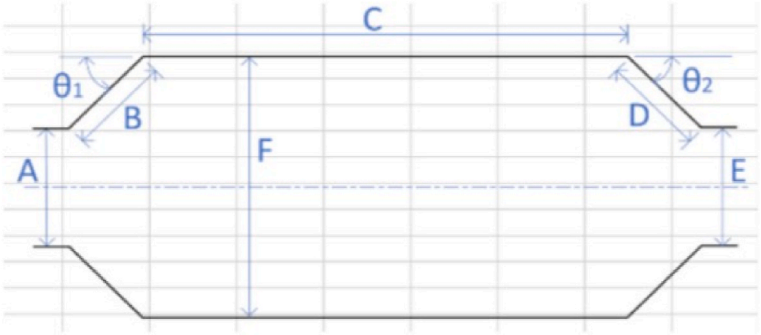


Fig. 1. Schematic design of ball mill.



Dimension							
A	B	C	D	E	F	θ1	θ2
(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(°)	(°)
1285	1735	5590	1735	1285	4725	82.5	82.8

Fig. 2. Dimension of ball mills shell.

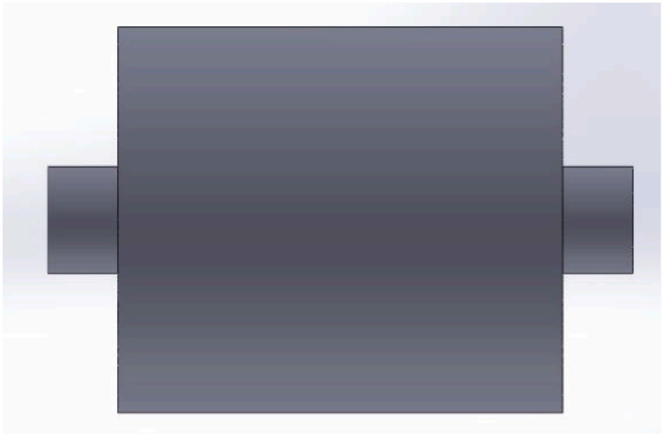


Fig. 3. Ball mill 3D reference model.

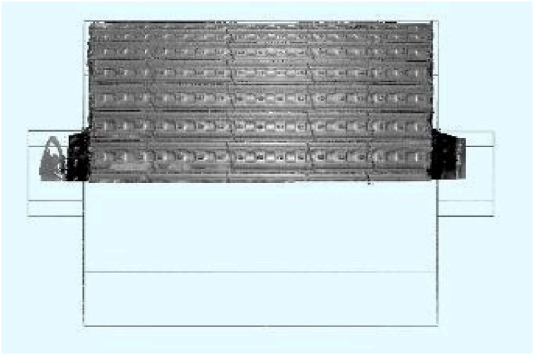


Fig. 4. Reference and profile comparison.

for characterization or detecting faults in contrast to specific criteria without changing the original characteristics or injuring the thing being tested [6]. The ultrasonic method is used to find internal flaws in materials that conduct sound. In some ways, echo sounding and ultrasonic testing work on the same principle. A brief ultrasonic pulse can be produced by applying an electric charge to a piezoelectric crystal, which vibrates for a very short time at a frequency correlated to the crystal's thickness. A laser scanner takes systematic measurements of the separations between the sensor and the item using laser light. The range component, which involves measuring distance, uses laser light to carry out the task. By reflecting the heavily collimated laser light, or beam, in various directions, a pattern is created that allows the range measurements to be acquired [7–12]. Because the predicted maintenance must generally be scheduled over a relatively short time range, quantitative forecasting is particularly essential in the actual operations of intelligent maintenance management systems. Simply historical state variable values, a mixture of state variable values and external variables, or only external variable values can be used to anticipate a defined future state of the system under maintenance. The quantitative forecasting approach might be based on a physical model in which the phenomena approximate a mathematical function. However, many events are complexly impacted by external influences, and a physical model is either unavailable or unreliable. In such instance, previous values of state variables serve as the foundation for quantitative forecasting, and we are

Table 2
Initial and limit dimension of ball mills liner.

Part		Initial Dimension (mm)	Limit Liner (mm)
Fedd Head	Lister	180	75
	Plate	100	30
Discharge Head	Lister	200	75
	Plate	100	30
Shell	Lister	135	65
	Plate	65	30

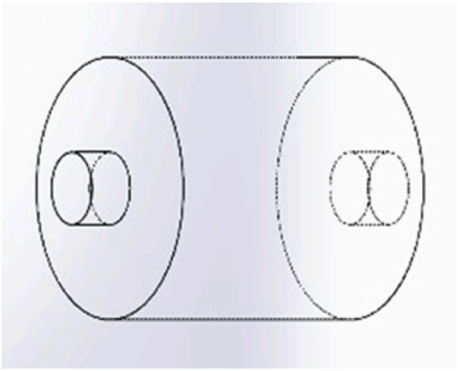


Fig. 5. Reference 3D model.

discussing data-driven models theoretically [13,14] (see Fig. 1).

2. Experiments

The initial stage marks the start of research operations and observations at one of mining industry in Indonesia. The next stage is problem identification, at this stage, a backdrop was developed to serve as a research basis to identify the current difficulties, particularly in carrying out predictive maintenance on liner ball mills using a 3D laser scanner and analyzing them using Geomagic Control X software to make forecasts for further maintenance. In order to complete the research objectives of studying ball mill liner wear analysis as a grinding machine for product processing, as well as forecasting in order to reduce downtime and create an effective schedule for parallel jobs, the data collection is required which entails gathering analytical data to meet the research objectives and calculating the research findings. This includes both primary and secondary data. After gathering the necessary data, the processing and modeling stages are carried out. The liner thickness inspection was performed on June 23, 2022, and the data collected is based on the inspection date, as shown in Table 1. During the inspection, a total of 8.59 Gigawatt-hours (GWh) and 1.69 Megatons (Mton) of power and mass were recorded, respectively. Figs. 2 and 3 are shows the dimension of ball mills shell and the three dimension (3D) reference model, respectively (see Fig. 4).

The ball mill shell diameter serves as a point of reference for the 3D comparison being discussed. A 3D reference model of a ball mill was developed to establish a standard for the thickness of the current ball mill liners. The condition of the 3D reference model represents a scenario in which the thickness of the liner has worn away, resulting in the model having no thickness or being an outline. The initial length and maximum length of the liner are describe in Table 2.

The liner materials in this study are a combination of metallics for the shell liner and Poly-met or as a combination of rubber and steel for

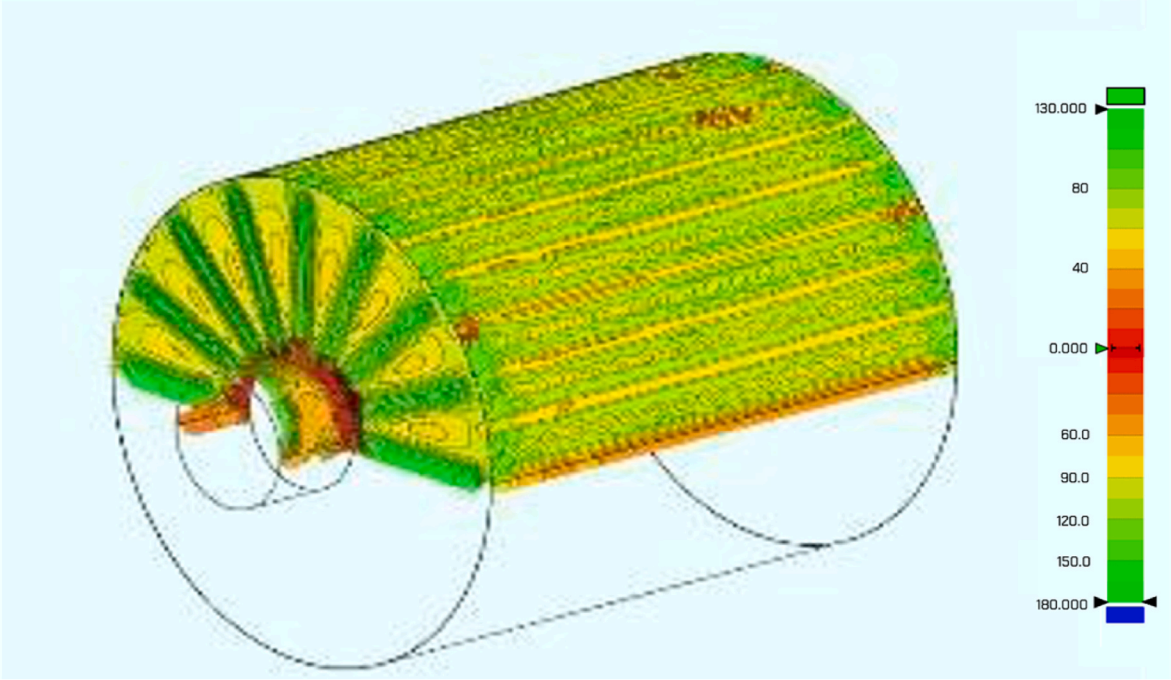


Fig. 6. 3D comparison.

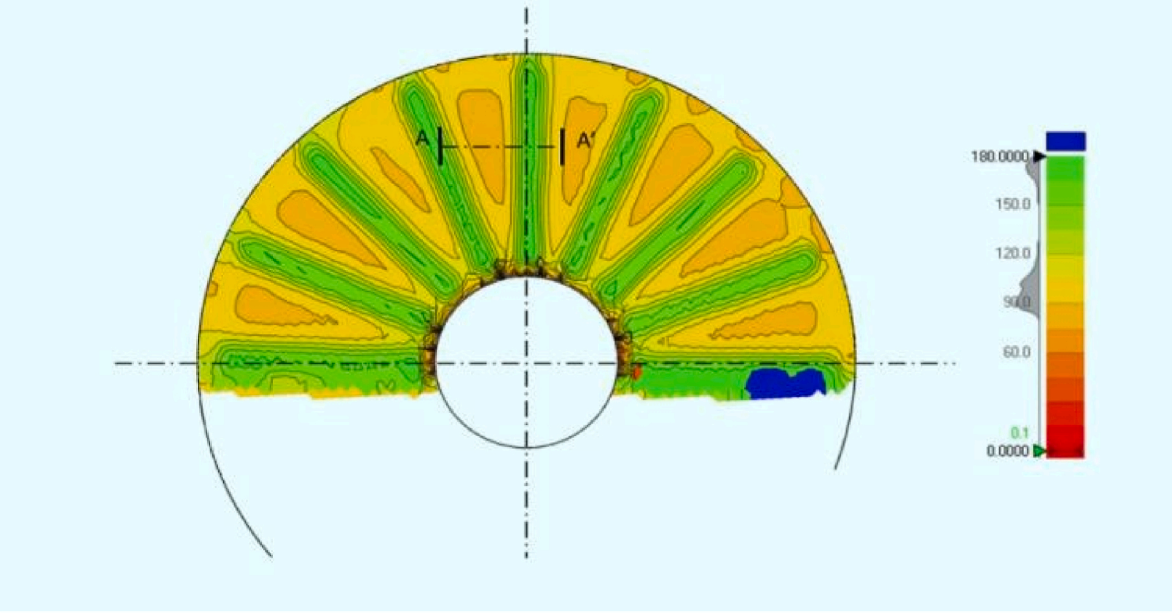


Fig. 7. Feed head liner wear.

the discharge and feed heads. Metallic materials have high chemical and temperature resistance, high charge pressure in large mills, abrasion caused by sharp particles, and use of special alloys for different applications. Meanwhile, poly-met has a long wear life and shock absorbing properties that reduce the risk of cracking, and its low weight causes less strain on the mill.

3. Results and discussion

The final step involves examining the collected data and comparing it to existing reference data, which is a model representing a ball mill liner with worn-out thickness. For this analysis, the program Geomagic Control X is used. Figs. 5 and 6 shows the reference, profile comparison, and 3D model, respectively. The analytical approach involves comparing each point on the profile data with the previously generated 3D model reference. The final output format is.CXProj. The comparison process is aligned with the reference data obtained during the data collection phase, as shown in Fig. 5. Consequently, a 3D comparison can be conducted to evaluate the distance between each point and the reference model (see Fig. 7).

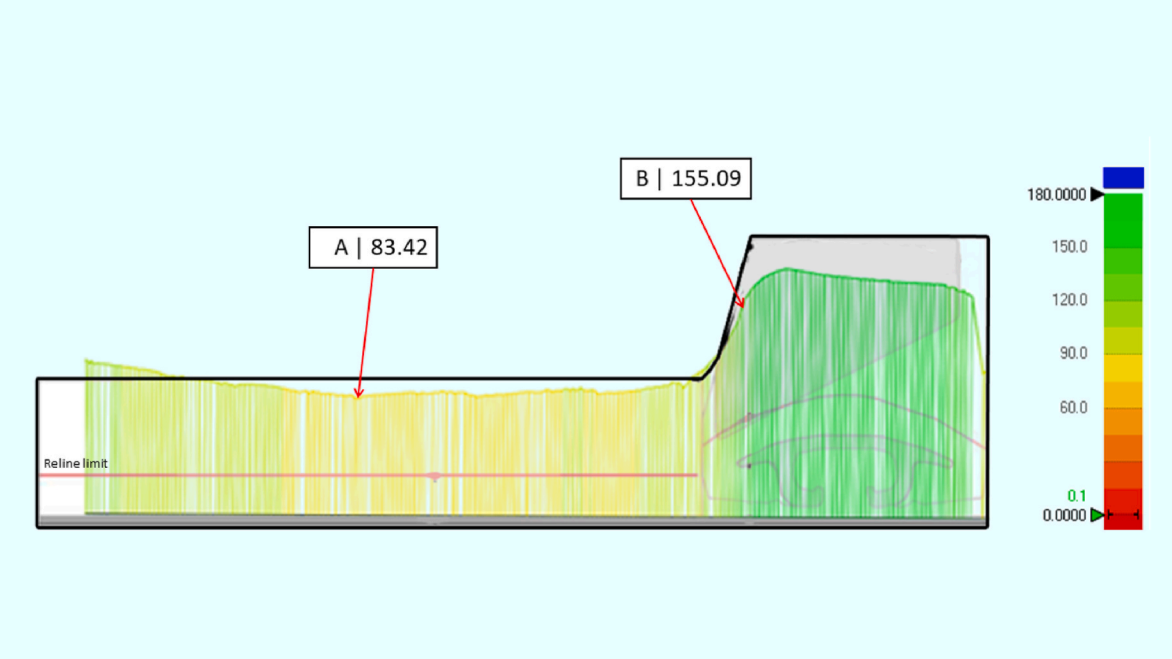


Fig. 8. 2D view of the feed head Liner (Section View A-A′).

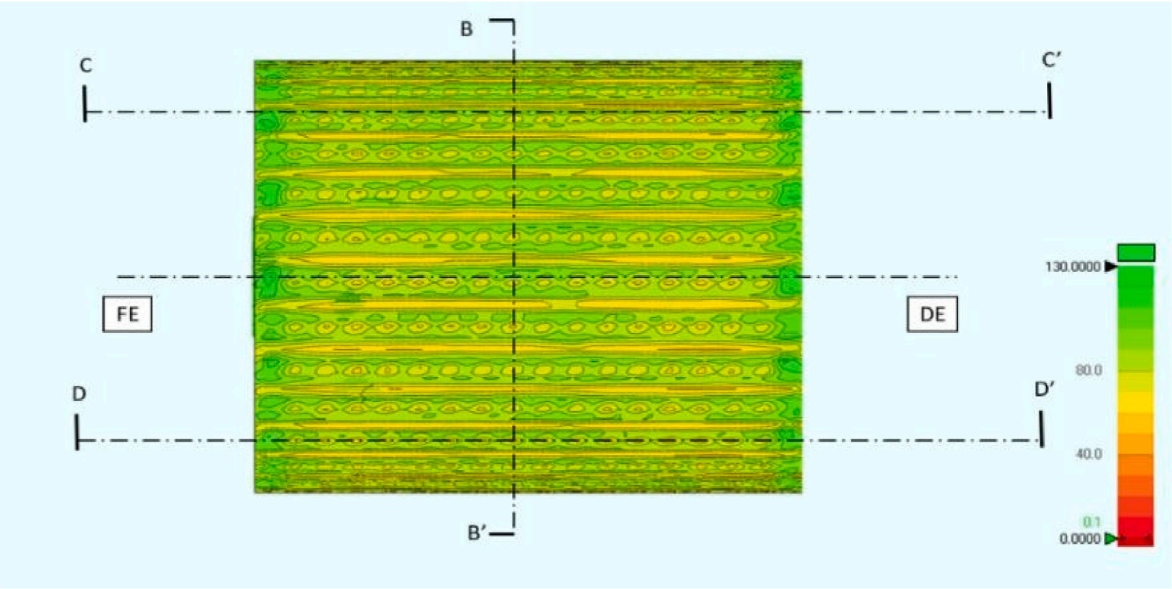


Fig. 9. Wearing on shell liner.

The lifter feed head has an initial thickness of 180 mm, whereas the plate has an initial thickness of 100 mm. The yellow and orange portions are known to have spacing between 50 and 80 mm, whereas the green area has a distance between 150 and 180 mm. Fig. 8 depicts the overall wear on the feed head. To view the wear of the feed head liner more clearly, cut one of the feed head liners that has the highest wear (orange hue).

At point A, the lowest point on the feed head plate measures 83.42 mm. The feed head lifter at point B has a minimum height of 155.09 mm. The plate is predominately yellow with a thickness of 80–90 mm, while the lifter is predominately green with a thickness of 150–180 mm, as indicated by their respective hues. As seen in Figs. 9 and 10, the wear on the shell liner is quite even. According to the figure above, the dominating hues are yellow, orange, and green. Yellow and orange are separated by 50–60 mm. The distance for the green color is between 100 and 130 mm. The shell plate has an initial thickness of 65 mm, while the lifter has an initial thickness of 135 mm.

As illustrated in Fig. 11, the shell plate at point C has the lowest point at 53.43 mm, while the lifter at point D has the highest point at 109.42 mm. As is generally known, the ball mill's axis of rotation is only one direction. On the one hand, this increases wear potential, as seen in Fig. 10 above.

The wear analysis of the plates and lifters along the shell is the next step in examining the lifters and plates as a whole. Figs. 12 and 13

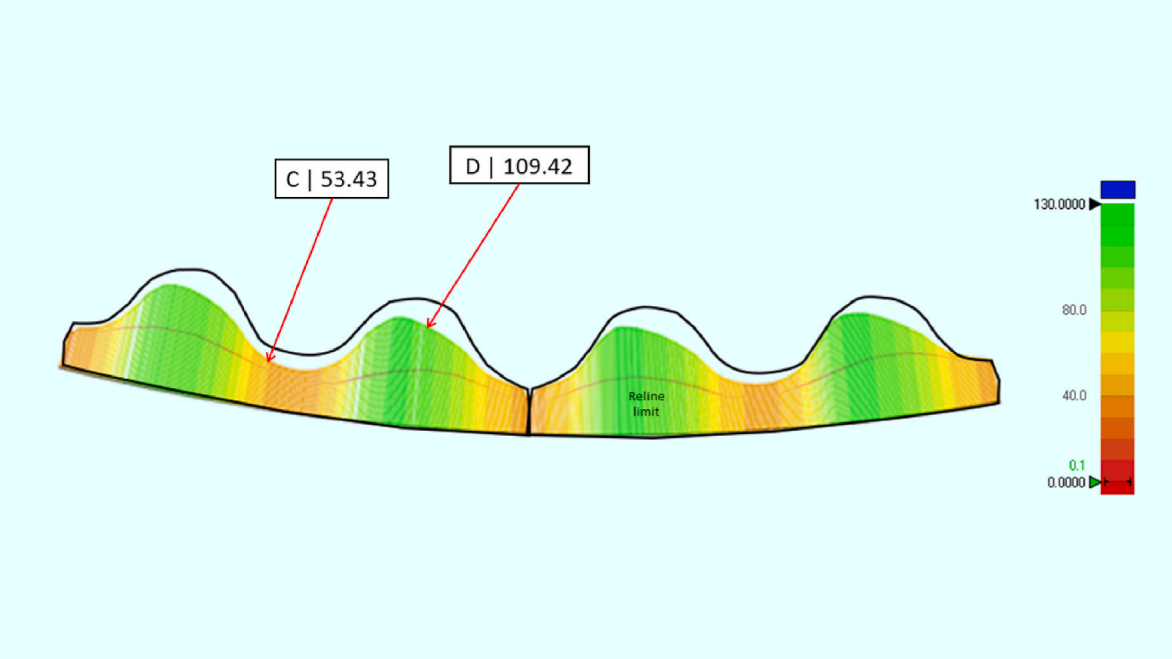


Fig. 10. 2D View shell liner row 2 (section view B–B′).

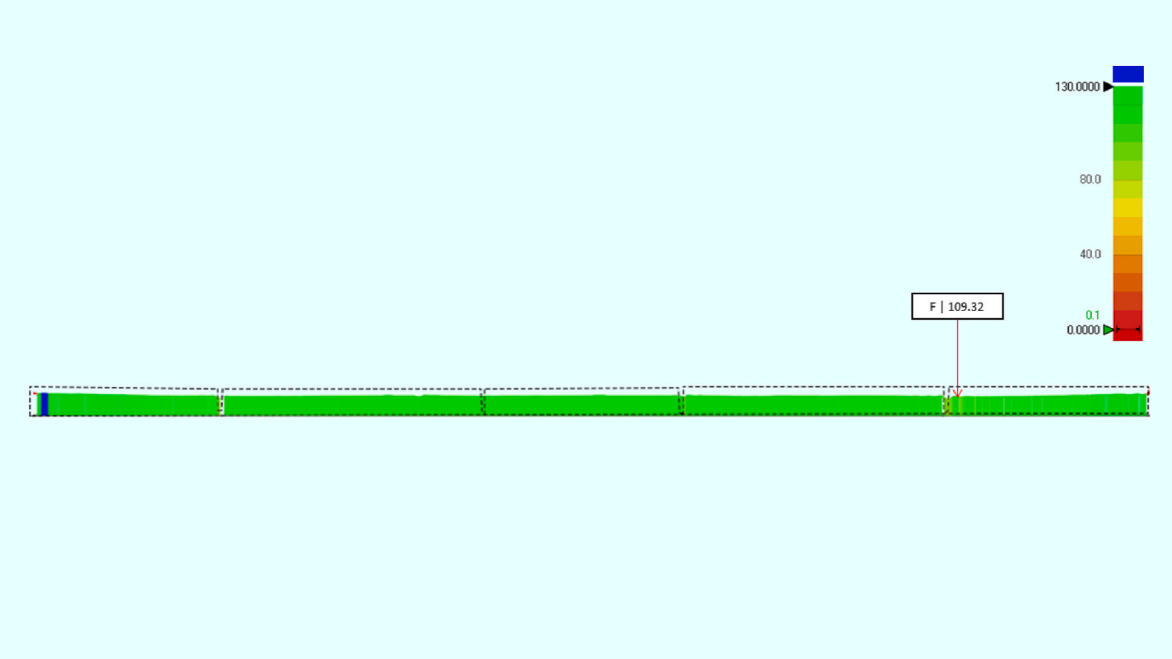


Fig. 11. Section view along shell lifter (section view C–C′).

illustrate wear in row 2 of the shell plate caused by the material being coarser at the entry than at the exit. The shell plate is meant to be 53.43 mm thick at point E, whereas the shell lifter is supposed to be 109.42 mm thick at point F. The discharge head lifter has an initial thickness of 200 mm, and the plate has a thickness of 100 mm. The plate thickness of the discharge head is the same as that of the feed head. In terms of the lifter itself, the initial thickness differs by 20 mm.

As shown in Figs. 14 and 15, the discharge head liner's lifter appears blue. The color blue indicates that the thickness in this region exceeds 180 mm, which is accurate given that the initial lifter discharge thickness is 200 mm. The red region, on the other hand, represents a trommel that is not part of the liner and can be ignored in the analysis.

The cut is caused by one of the discharge liners that has seen the most wear. The plate at point G of the discharge head liner has a thickness of 81.20 mm, and the lifter at point H of the discharge head liner has a thickness of 165.18 mm. Interpolation may be used to look for surveillance and producing forecasts. As a result of the surveillance, the following results were obtained from determining the function of an

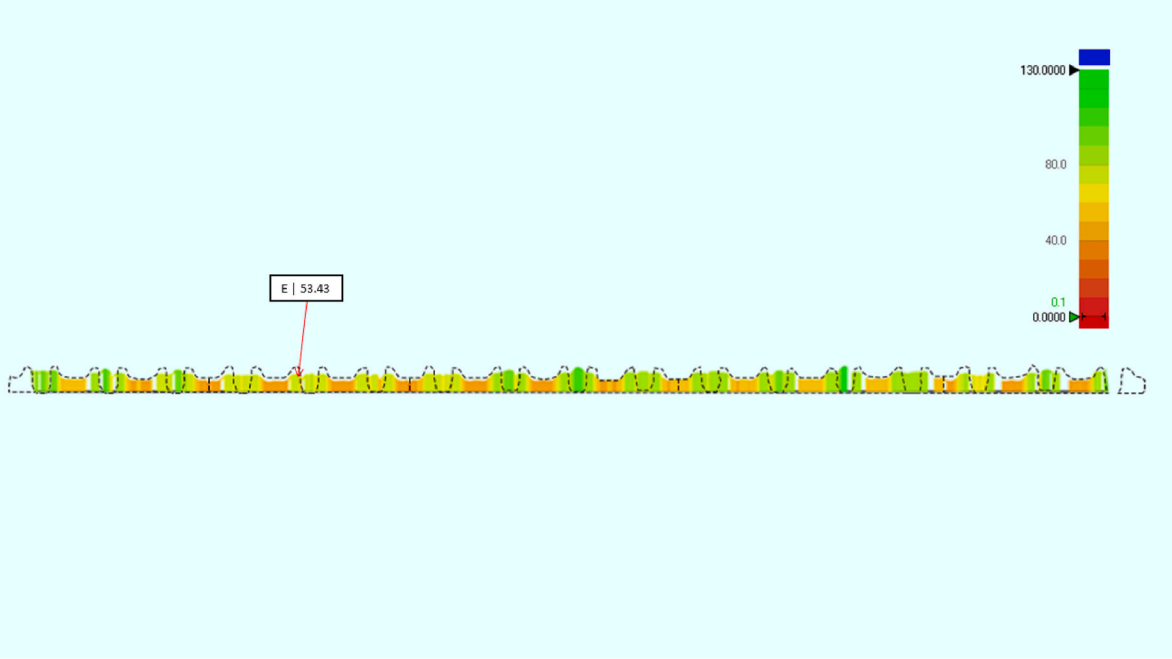


Fig. 12. Section view along shell plate (section view D-D').

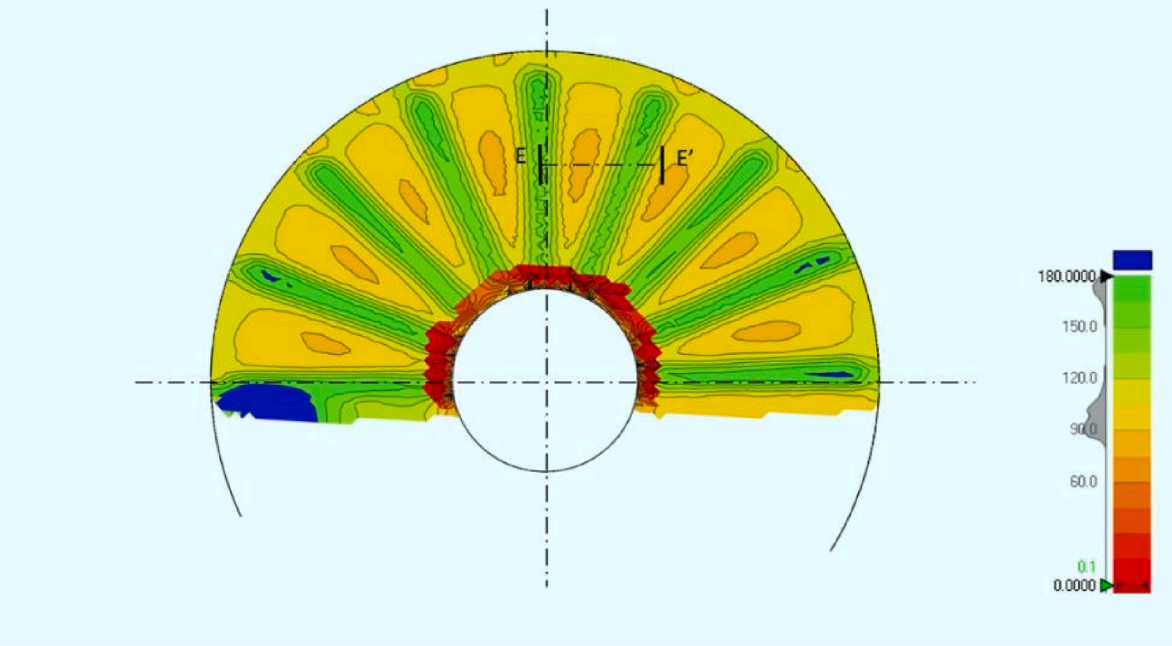


Fig. 13. Wearing on discharge head liner.

existing variable by using two known variables, as shown in Table 3.

The preceding table indicates that the feed head liner will be replaced at the beginning of 2024, the discharge head liner will be replaced near the end of 2023, and the shell liner will be replaced in the middle of 2023. The below graph relates the thickness of the feed head lifter liner to the supplied power (GWh). The thinner the appearance of the lining, the more power is released. Similarly, the time and tonnage input are always inversely proportional to the thickness of the liner. A straight or linear trend line will then be formed. Interpolation is one technique for creating new variables from two known variables in order to determine the function of a trend line. After determining the function of the trend line, we may look for the appropriate variable, as illustrated in Fig. 16, which looks for power when the liner thickness of the feed head lifter is 75 mm. Power is produced when the thickness of 75 mm reaches 36,078 GWh. This calculation applies to all liners.

Based on the results of the ultrasonic testing depicted in Fig. 17, the ball mill liner segment or part 4 has the thinnest shell. This is due to the fact that the position of the ball mill is inclined by approximately 10° to allow the material to exit, resulting in the majority of wear occurring at the end of the ball mill.

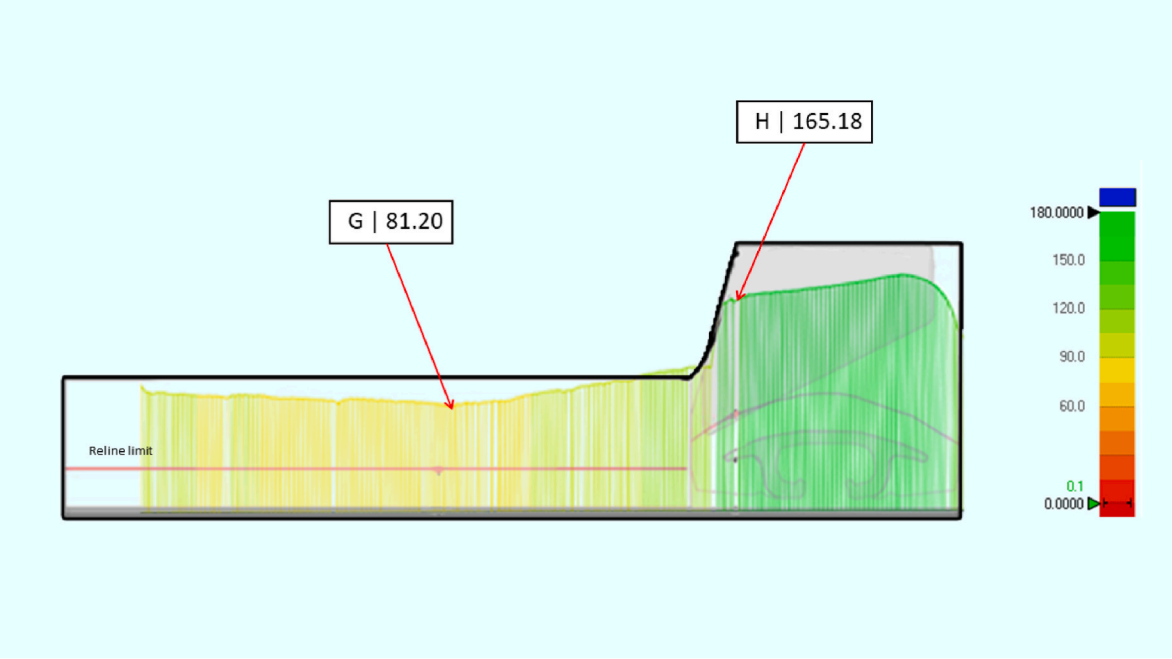


Fig. 14. 2D View discharge head liner (section view E-E′).

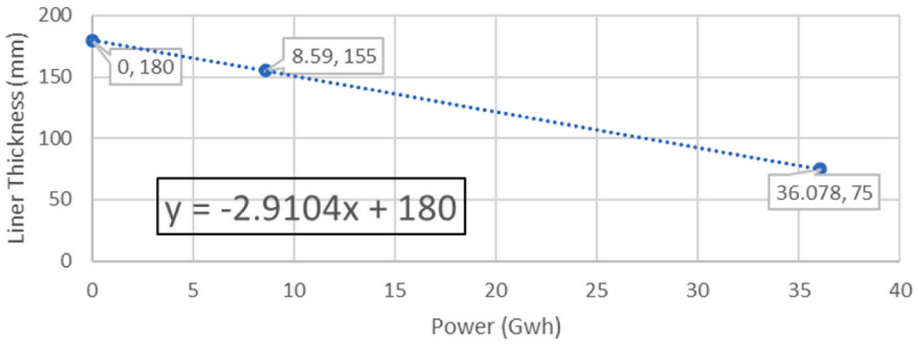


Fig. 15. Trendline graph.

Based on the collected data, 52 mm is the minimum liner thickness for the shell plate of the ball mill. The completion date for relining can be estimated to be May 3, 2023, given the current wear rate and usage, as shown in Table 4. Fig. 5 shows the ball mill relining timeline from 2017 to 2022.

The average age of the ball mill is one year and seven months, according to data provided specifically for the relining of the ball mill. The liner of the ball mill will be replaced on May 19, 2023, according to the results of an analysis of liner wear conducted on June 23, 2022. This means that the ball mill will be one year and five months old. The obtained results are comparable to the average liner age of all ball mills. In addition, the use of 3D laser scanning to produce forecasts is beneficial in other areas. According to Ref. [15], "3D laser scanning allows for quick and full-coverage documentation of a cavity's excavated geometry at high resolution. In recent years, the use of laser scanning technologies for documentation and to help solve geotechnical concerns has become common in tunneling." This demonstrates that the 3D laser scan approach may be used not only to help forecast the life of the liner, but also in other fields, making the 3D laser scan method highly practical and efficient in terms of forecasting. Based on the forecast, a comparison of the ultrasonic testing method with the 3D laser scan method is as follows.

Table 5 shows that the laser scanning approach is more efficient when performing an inspection. Laser scanning is faster and easier to perform. The laser scan technique allows for the evaluation of not only the inspection time but also the results of wearing, whereas ultrasonic testing is solely dependent on the documentation collected during the inspection.

4. Summary

According to the findings, relining or changing the liner on the Feed and Discharge Head may be performed in roughly a year. The shell will be finished in 9 months. This is due to the shell liner being the most frequently impacted by the ball mill ball and material, resulting in a shorter life for the shell liner than the head liner. The total lifespan of the

Table 3
Result of forecast based on wearing analysis on ball mill liner.

	Feed Head Lifter			
	Date	Power (GWh)	Tonnage (Mton)	Thickness (mm)
	2021/12/19	0	0	180
	2022/06/23	8.59	1.69	155
Forecast	*2024/02/08*	*36.08*	*7.10*	*75*
Deviation		27.49	5.41	
	Feed Head Lifter			
	Date	Power (GWh)	Tonnage (Mton)	Thickness (mm)
	2021/12/19	0	0	200
	2022/06/23	8.59	1.69	165
Forecast	*2023/10/14*	*30.68*	*6.04*	*75*
Deviation		22.09	4.35	
Feed Head Lifter				
	Date	Power (GWh)	Tonnage (Mton)	Thickness (mm)
	2021/12/19	0	0	135
	2022/06/23	8.59	1.69	109
Forecast	*2023/05/03*	*23.13*	*4.55*	*65*
Deviation		14.54	2.86	
	Feed Head Lifter			
	Date	Power (GWh)	Tonnage (Mton)	Thickness (mm)
	2021/12/19	0	0	100
	2022/06/23	8.59	1.69	83
Forecast	*2024/01/24*	*35.37*	*6.96*	*30*
Deviation		26.78	5.27	
	Feed Head Lifter			
	Date	Power (GWh)	Tonnage (Mton)	Thickness (mm)
	2021/12/19	0	0	100
	2022/06/23	8.59	1.69	81
Forecast	*2023/11/04*	*31.65*	*6.23*	*30*
Deviation		23.06	4.54	
	Feed Head Lifter			
	Date	Power (GWh)	Tonnage (Mton)	Thickness (mm)
	2021/12/19	0	0	65
	2022/06/23	8.59	1.69	53
Forecast	*2023/06/14*	*25.05*	*4.93*	*30*
Deviation		16.46	3.24	

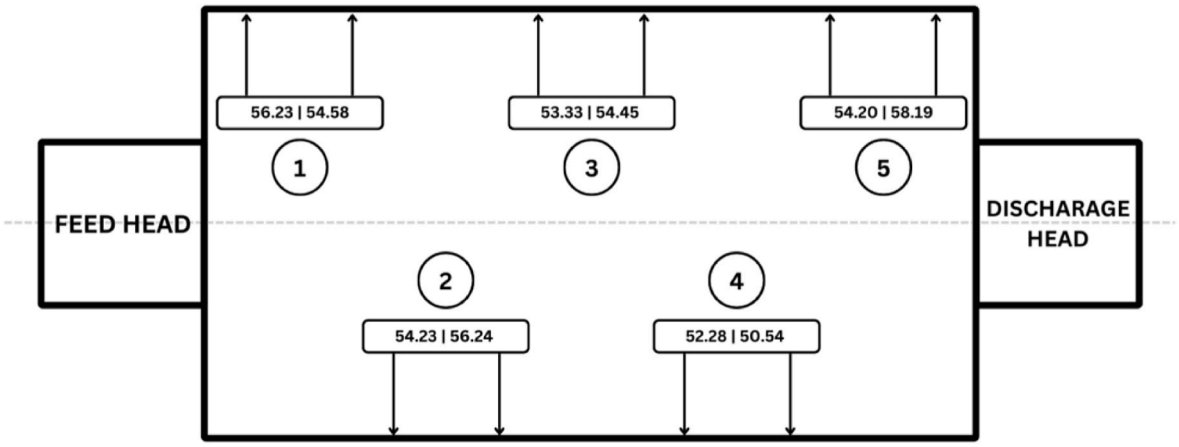


Fig. 16. UT Result on Shell Liner using 38DL Thickness Gauge in mm.

shell liner may be estimated to be one and a half years, while the lifespan of the head liner can be estimated to be two years. The laser scan approach is more effective than ultrasonic testing. This study concludes that the time required for laser scanning is less than that required for ultrasonic testing, saving more time while producing the same results. Based on the discussion, the estimated age of the ball mill liner is comparable to the average age of the previous liner replacement, which was one year and seven months on average, rendering the forecasts and analyses valid. The 3D laser scanning approach is also useful in another area of forecasting, demonstrating that it is both practical and efficient. A forecast is an assumption about what exists now and what is expected to happen in the future. Consequently, the assumption is not always correct. The obtained results are the result of calculations and studies performed in order to determine the life of the ball mill liner.

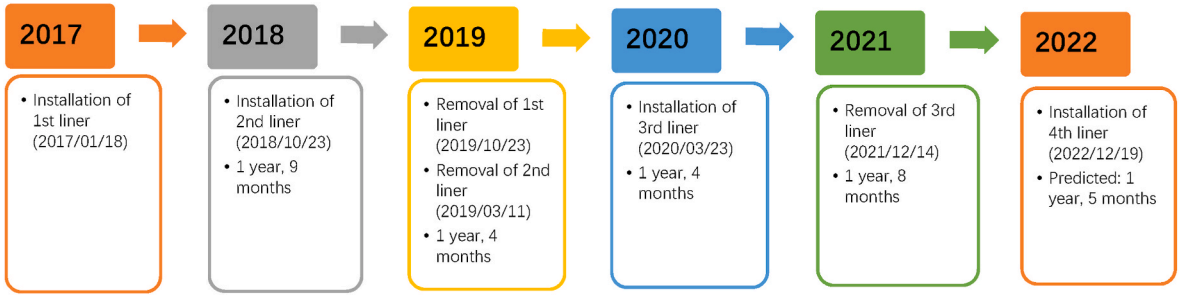


Fig. 17. Ball mill relining timeline.

Table 4
Forecast results based on ultrasonic testing method.

	Shell Plate			
	Date	Power (GWh)	Tonnage (Mton)	Thickness (mm)
	2021/12/19	0	0	65
	2022/06/23	8.59	1.69	52
Forecast	*2023/05/03*	*23.13*	*4.55*	*30*
Deviation		14.54	2.86	

Table 5
Comparison method table.

Findings	Methods	
	Laser Scanning	Ultrasonic Testing
Time taken	5–7 min	7–12 min
Efficiency	Relatively easy and more efficient	Takes time and must be measured one by one
Results of relining (based on lowest thickness)	2023/05/03	2023/05/03
Results of wearing	Direct can review after laser scanning	Only based on documentation

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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