Investigation of the Cylinder Liner Wear in Agricultural Tractors

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Abstract

The present study aimed to examine the application of accurate and principle-based evaluations of a measuring instrument called the Form Tester in determining and detecting the wear phenomenon in the cylinder liner of agricultural tractors. For this purpose, a cylinder liner of the Perkins 4-248 engine (related to the Massey Ferguson 285 tractor) manufactured by Keyhan Sanat Ghaem Company was used. The geometric parameters that were measured in this research included roundness, straightness, and concentricity of the cylinder liner. The evaluations on roundness and concentricity of cylinder liner were conducted in 12 circular positions with the same longitudinal distances. The straightness was measured in five lines with the same longitudinal distances in 90° around the cylinder liner environment. The results of the measurements were discussed and analyzed to evaluate the engine status along the functional path of the piston within the cylinder liner. The degree of deviation rate of the parameters indicated significant wear within the cylindrical liner. The wear rate in cross-sections at high and low dead points was significantly greater than that of the same cross-section in the vicinity of the midpoint of the piston movement path inside the cylinder, as well as the cross-sections near the high dead point. The results of this research provide feedbacks for engine designers to apply various changes to the engine and for maintenance and repair engineers to ensure the correct implementation as well as preventive and predictive repair and maintenance strategies.

Keywords: Cylinder liner, Tractor, Geometric tolerances, Wear, Honing process

1. Introduction

Nowadays, the process of mechanization development highlights that an increase in the operating of agricultural tractors and mechanical power-sharing improves agricultural production. On the other hand, the development of agricultural mechanization heavily relies on how to use this source of power production and how to use the agricultural tractor as the main source of power production. (Karimi et al., 2012; Afsharnia et al., 2014; Khodabakhshian and Sajadi, 2022). The optimal use of the tractor depends on the quality and durability of its fast-moving parts. If the quality of the parts is not at the desired level, their breakage and wear will cause unwanted stops in the field, and this will affect the technical performance and the economic efficiency of the machine. Therefore, the probability of failure, repair time, and its causes should be considered in the processes (Rohani *et al*., 2011). In this regard, the rapid development of tractor manufacturing has led to growing expectations for improving the performance of the tractor's engine. Hence, increasing the precision of machining the engine parts of the tractor including the cylinder liner plays a vital role in enhancing the production power of the engine and reducing the fuel consumption, in addition to the direct impact on the amount of burning oil in the engine and satisfying emission standards (Khodabakhshian and Shakeri, 2011;Söderfjäll *et al*., 2016; Kılıç and Temizer, 2016).

Surface roughness after honing operation is regarded as one of the most important parameters in determining the accuracy of machining the cylinder liner. Regarding the Honing process, which is very similar to the grinding process, lines with angles of 45 to 55 degrees are created in the cylinder inner surface by abrasive stones using a specially designed machine to maintain engine oil in these grooves, keep the cylinder wall lubricated, prevent the piston from blocking, minimize the wear of the cylinder liner, and reduce the frictional losses of the engine. For each engine, the designer determines patterns and angles of furrows and grooves of Honing to a certain extent. However, if these grooves are created at a much higher angle than the specified value, oil cannot remain in these grooves and returns to the cartel, due to gravity. This trend causes engine rattling, reduces the useful life of the parts, and results in failure. However, if the angles of these grooves are less than the limit, they cause the remaining oil volume in the cylinder wall to be more than the limit, resulting in burning oil in the engine and oil shortage, which can damage other parts (e.g. Bearings and crankshaft) due to the reduced oil pressure (Sudarshan and Bhaduri, 1983; Cabanettes *et al*., 2015; Buj-Corral *et al*., 2017).

The Honing process improves the geometric shape of the cylinder liner in terms of its geometric properties, including ovality and conicalness. The ovality of the cylinder because of creating an asymmetric contact surface between the rings and pistons with the cylinder liner wall, increases the friction in the engine and the wear between the ring and the cylinder liner wall. This phenomenon results in the increase of the fuel consumption and the reduction of the output power of the engine and consequently, the useful life reduction of the engine parts over time, with excessive wear between the ring and piston with the cylinder wall (Kim *et al*., 2018). In some cases, it has been observed that the liner surface roughness from its allowed range can cause the escape of combustion flame from the contact surface between the ring and the cylinder liner wall and lead to engine power loss and excessive temperature rise, and ultimately, the occurrence of piston seizure (Yusefi *et al*., 2015). Thus, Tractor Manufacturing Companies now apply stricter standards with tight tolerances in the allowed level of cylinder liner roughness, although these standards are different depending on the engine type and the diameter of the cylinder and piston. The precise prediction of Honing parameters reduces the cost of repairs, decreases the time lags for using tractors, provides efficient planning, increases safety, allows financial savings, and enhances economic returns. The optimization of the Honing machine parameters is considered as one of these management systems in the production of cylinder liners (Cabanettes *et al*., 2015; Kim *et al*., 2018).

In Iran, few studies have been conducted to determine the effect of Honing parameters on the geometric properties and the wear rate of the cylinder liner in agricultural tractors, as well as the impact of the Honing parameters on the engine functional parameters. Most studies carried out in this area have predicted the maintenance and repair costs of agricultural tractors and determined the economic life of tractors (Almasi and Yeganh, 2002; Khodabakhshian and Shakeri, 2011; Rohani *et al*., 2011). Some researchers have studied the use of the preventive maintenance for agricultural machines (Khodabakhshian *et al*., 2008a, b). Buj-Corral *et al*. (2015) conducted a study in an industrial company and developed models for optimizing the Honing equipment of the driving liner, by comparing the data obtained from the surface roughness test device in the laboratory and the existing Honing machine. In another study, Cabanettes *et al*. (2015) collected information about the surface roughness of the cylinder liner and its associated wear. Yusefi *et al*. (2015) examined the impact of Plateau Honing parameters on the surface roughness of the driving cylinder liner. Kim *et al* (2018) discussed the effects of Plateau Honing parameters on the friction and wear of the driving cylinder liner.

Furthermore, several studies have been conducted on the correlation between the surface roughness of driving cylinder liner and the Honing parameters by other researchers (Andersson and Tamminen, 2002; Jayadas, *et al*., 2007; Ramadan *et al*., 2009; Klein *et al*., 2017). However, no information was found regarding the effect of Honing parameters on the wear rate of the cylinder liner of agricultural tractors.

The present study presents a precise dimensional and geometrical evaluation on the internal surface of the cylinder liner in agricultural tractors to control the degree of wear variation, which is related to the geometric deviations and changes in the directions of transverse (the cylinder liner is not roundness) and longitudinal (the cylinder liner is not cylindrical) paths. For this purpose, a cylinder liner of the Perkins 4-248 engine (related to the Massey Ferguson 285 tractor) manufactured by KeyhanSanatGhaem Company was used to conduct the test. The measured geometric parameters included the roundness, straightness, and concentricity of the cylinder liner.

2. Materials and methods

2.1. The spatial and temporal domain of research

Keyhan Sanat Ghaem Company, as one of the largest manufacturers of cylinder liners in Iran and the Middle East, was selected as the case study. The current research was conducted in 2021 in this company. Given the purpose of the study, 25 cylinder liners of the Perkins 4-248 engine, which was related to the Massey Ferguson 285 tractor were selected (Fig. 1).

Fig. 1. A sample of the cylinder liner

The tested cylinder liner material is made of high-quality cast iron (GG 25) with a diameter of about 101 mm. Table 1 presents the chemical analysis and mechanical properties of cylinder materials, in which HB represents the hardness range in terms of Brinell.

Table 1. Cylinder liner material specifications

Mechanical Properties		**Chemical Properties (wt. %)**					
Tensile Strength (MPa)	Hardness (HB)	Cr%	S%	P%	%Mn	%Si	%C
Min.225	235	0.5	0.1	0.4	0.9	2.4	3.35

2.2. Measuring parameters

The dimensional and geometric specifications of the studied cylinder liner were measured and evaluated using the Formtester MMQ 44, Mahr Company, Germany equipped with the LSQ computational algorithm in the metrology laboratory of the Keyhan Sanat Ghaem Company (Fig. 2). The Formtester device applied in this work was, in fact, a special cylinder liner, which was able to produce correct and principle results with consistent repeatability in the geometric deviations of the liner's inner surface. The approximate transfer speed of the Formtester was $20\,mms^{-1}$ and the approximate scanning speed of the test device rod during the evaluation period was$20\,mms^{-1}$. The evaluations on the roundness and concentricity of the cylinder liner were conducted in 12 circular positions with the same lengthwise distances (Fig. 3). Additionally, the straightness was measured in 5 lines with the same lengthwise distances in 90° around the cylinder liner environment.

Fig. 2. The Formtester used for measuring dimensional and geometric specifications of cylinder liner

All dimensional and geometric specifications of the surface were evaluated with average values of five evaluation tests. The data were analyzed using descriptive statistics such as mean (M), standard deviation (S_D), and combined standard uncertainty (U_C), which is calculated according to the Eq. (1).

$$U_C = \frac{S_D}{\sqrt{n}} \qquad (1)$$

Where n represents the number of repetitions of measurements.

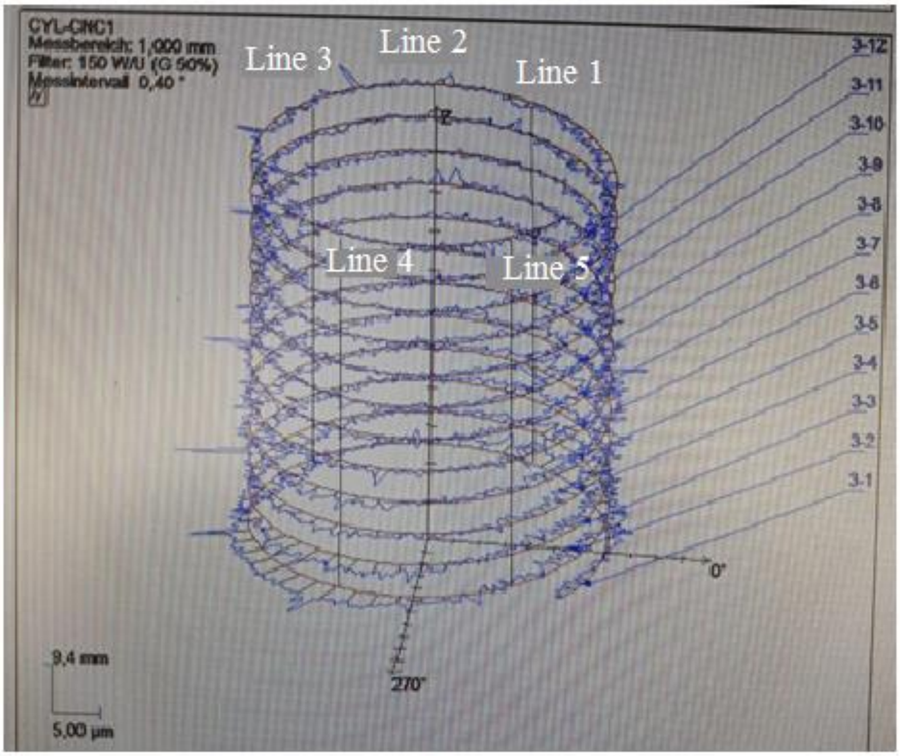

Fig. 3. The position of sections for roundness and straightness measurements

3. Results and discussion

3.1. Evaluating the uncertainty of measured values: roundness

Table 2 shows the values of the mean, standard deviation (S_D), and combined standard uncertainty (S_D) of roundness measurements for the cylinder liner of Messier Ferguson 285 tractor in the five studied sections (Fig. 3). Due to the relative importance of roundness values and straightness outside of the interval, uncertainty by method B (the method obtained from data and information as a result of previous measurements, experience with general knowledge of physical behavior, properties, tools and specifications provided by the manufacturer were not taken into account for combined standard uncertainty values. As a result, the combined standard uncertainty was only evaluated using method A (based on measurements performed in repeatable conditions). The accuracy and uncertainty of all evaluations were carried out within the standard limits authorized by the manufacturer (customer).

Table 2. Mean, standard deviation, and combined standard uncertainty of roundness measurement

Measuring Position	Repeat 1	Repeat 2	Repeat 3	Repeat 4	Repeat 5	Mean	S_D	U_C
Roundness values (µm)((Based on the minimum error of the crossing circle with the diameter of the cylinder liner from the relevant section)								
Circle 1	18.5	18	18.8	18.9	18	18.44	0.4278	0.1913
Circle 3	25	24.5	24.9	24.7	24.8	24.78	0.1924	0.0860
Circle 6	28.3	28.6	28.7	28.6	28.4	28.52	0.1643	0.0735
Circle 9	37.2	37.3	36.9	36.8	37.1	37.06	0.2074	0.0927
Circle 12	82.5	82.6	82.8	83	83	82.78	0.2280	0.1020

3.2. The results of the roundness measurement values outside the interval

The results of the average values of roundness outside the customer's expected range (Ra values) examined for five samples of the studied sections were presented in Figure 3 for the inner surface of the tested cylinder liner with the nominal internal diameter which was measured in Figure 4. This amount of roundness was measured based on the passage of two peripheral and intersecting circles from the cross-sectional profile of the part in the studied section, which was done using the LSQ computational algorithm programmed on the Formtester. The following cases can be concluded according to the analysis performed on the roundness patterns of the internal surface of the cylinder liner illustrated in Fig. 4.

As expected, in the section related to Circle 12 (which is close to the high point of death) due to oil shortage, the highest deviation from the nominal dimension was 102.1152 mm and also the highest value of the mean roundness outside the interval was 82.9 µm which was obtained in this section. As shown in Fig. 4, the smallest deviation from the nominal dimension is 102.0125 mm in the vicinity of the piston stroke midpoint(piston return path) (section 6) while the roundness outside the interval in the circle related to this section is about 28.8 µm. However, the lowest amount of roundness near the dead point (circle 1 related) was obtained at 18.7 µm.

As mentioned, the lowest amount of deviation from the nominal dimension as well as the relatively small amount of roundness was related to the circular cross section No. 6, which had the least inner surface wear changes of the cylinder liner. The reason for low fluctuation at this position may be due to good lubrication and low lateral forces imposed on the piston.

Although the circular section adjacent to the low dead point (section 1) represented the lowest roundness outside the interval, the variation rate of this parameter was higher at this section, which can be perceived from the amount of deviation resulting from the measurement results in this section (Table 2). This issue may be related to the position of the retaining forces of connecting rod while passing this section. In general, in sections near the low and high dead points, the variation rate of roundness outside the interval was more perceptible, due to the same retaining forces of the connecting rod during the piston passage (Table 2).

According to the above results and Figure 6, it was concluded that the device software generates a geometric index reference from the ideal and accurate shape of a number of one or more irregularly scanned sections that provide information and reference data related to the sections which can be utilized in evaluating the final values of the geometric indices of the investigated section.

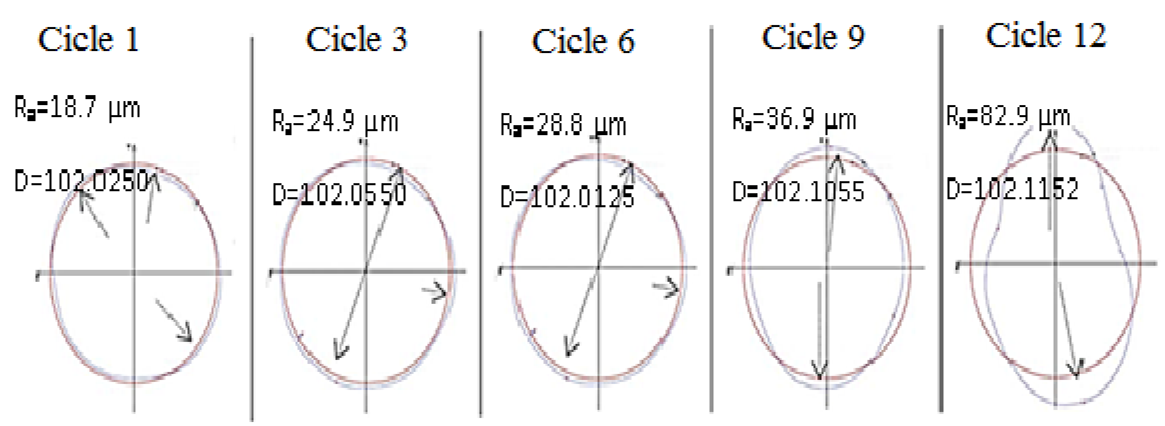

Fig.4. Roundness measurements and diameter records of the internal surface of the cylinder liner in the studied cross-area position

3.3. The results of concentricity measurement values

Given the values of the roundness measurements on the internal surface of the cylinder liner in different transverse positions, the concentricity values of 60.6, 52.5, 45.4, and 28.5 µm were obtained between circles 12 and 1, 12 and 3, 12 and 6, and 12 and 9 around the vertical axis demonstrated in Fig. 3, respectively. These results justify the values of the deviation from the nominal dimension resulting from the severe wear mechanisms in the cylinder liner, which are observed during service and maintenance.

3.4. The results of straightness measurement values outside the interval

For example, Fig. 5 shows a report of five lengthwise profiles in the positions of 12 sections studied along the internal surface of the cylinder liner. The maximum straightness value (S_a) obtained from measurements along each longitudinal profile indicates the deviation extent of the domain around the guideline of the cylinder liner (vertical axis in Fig. 3) derived from the appropriate LSQ technique.

The results of the straightness values related to five profiles addressed in Fig. 5 elaborate on the following points:

Uneven wear is perceived along with all longitudinal profiles. Each point on the inner surface of the cylinder liner is exposed to different environmental and dynamic conditions of pressure, friction, lubrication pattern, slip speed, the temperature at the point of contact, and contact force. Therefore, it is necessary to evaluate the fluctuations of the geometric condition of the inner surface of the cylinder liner to predict the signs of surface failure. Each point on the inner surface of the cylinder liner is exposed to different environmental and dynamic conditions of pressure, friction, lubrication pattern, sliding speed, point of contact temperature, and contact force.

The maximum wear rate was always obtained at the contact surface of the first piston rings at the high dead point with mean values of 80.2, 60.6, 32.5, 18.2, and 44.4 μm for the longitudinal profiles related to the lines 1, 4, 5, 3, and 2, respectively (Fig. 3). These cases can be justified by adverse and undesirable tribological conditions at the TDC position. As stated, the maximum straightness deviation (80.2 μm) in the longitudinal profile 1 during the impact period is formed as a quick direct reaction force to the lateral force response at high combustion temperatures. These results and findings are in coinciding with the studies conducted by El-Sherbiny., (1982), Schneider *et al*., (1993),Kilic *et al*., (2007),Nabnu *et al*., (2008), Bocchetti *et al*., (2009), and Kumar *et al*., (2015).

The amplitude of the grooves associated with the true tolerance of the inner surface of the cylinder liner showed the highest value for the longitudinal profiles 1 and 4 near the low point of death due to the lateral inertia reaction of the piston, while the longitudinal profiles 5 and 3 showed the lowest amplitude, respectively.

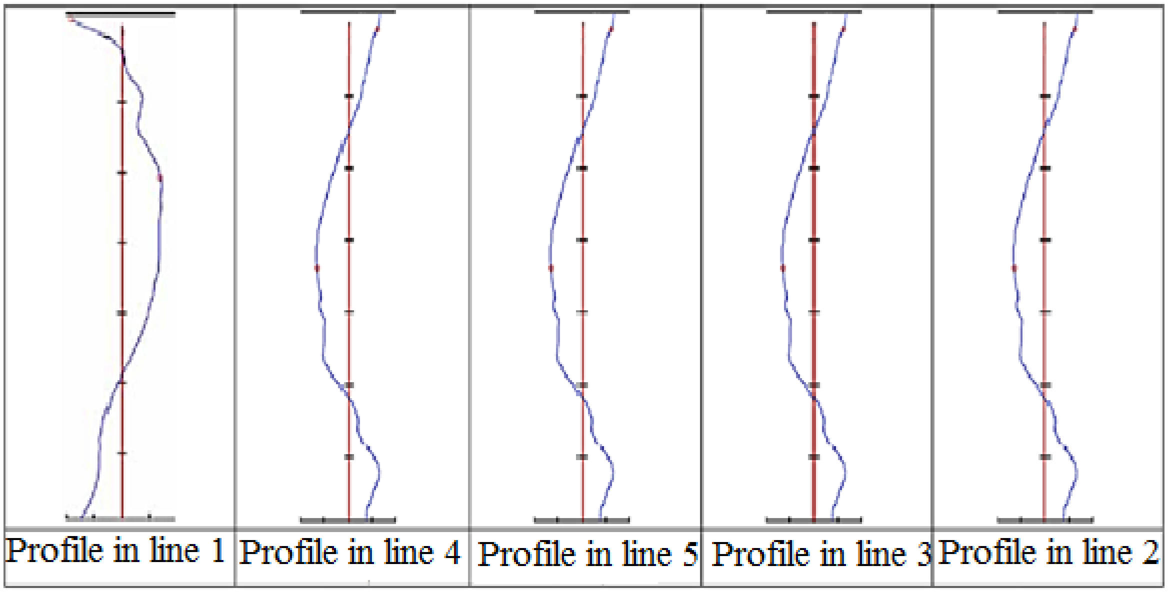

Fig. 5. Straightness measurements of the internal surface of a cylinder liner in the studied cross-area situation

4. Conclusion

In the present study, geometric measurements of the inner surface of the cylindrical liner were carried out using a Formtester device. Compared to the design tolerance interval (provided by the customer), the measurements indicated that the Formtester device is a new acceptable diagnostic tool for controlling wear and error rate. The dimensional evaluation of the inner diameter of the cylindrical liner in various transverse positions (12 studied sections) along the piston movement path within the cylinder confirmed the previous results and findings, which were obtained using other more sophisticated evaluation techniques.

Wear at transverse sections at high and low dead points was significantly greater than that of the same transverse section in the vicinity of the piston movement midpoint inside the cylinder, as well as the transverse sections adjacent to the high dead point. This phenomenon is due to the presence of the engine oil layer maintained in that position.

Investigating the straightness of the cylinder liner at the position of the studied sections indicates non-uniform wear along with all the longitudinal profiles. The maximum wear rate was always at the contact surface of the first piston rings at a high dead point with mean values of 80.2, 60.6, 32.5, 18.2, and 44.4 μm for the longitudinal profiles related to the lines 1, 5, 4, 3, and 2, respectively. The results of this research can provide feedbacks for engine designers when applying various changes to the engine, as well as maintenance and repair engineers to ensure the correct implementation and suggest predictive and preventive maintenance strategies.

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بررسی سایش بوش سیلندر در تراکتورهای کشاورزی

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چکیده

در این تحقیق کاربرد ارزیابی‌های دقیق و اصولی یک دستگاه ابزار اندازه‌گیری به نام فرم تستر در تعیین و تشخیص پدیده سایش در بوش سیلندر تراکتورهای کشاورزی مورد مطالعه و ارزیابی قرار گرفت. بدین منظور از بوش سیلندر موتور پرکنیز ۴/۲۴۸ مربوط به تراکتور مسی-فرگوسن ۲۸۵ تولیدی شرکت کیهان صنعت قائم استفاده گردید. پارامترهای هندسی اندازه‌گیری شده شامل گردی ، تلرانس راستی و هم مرکزی سطح داخلی بوش سیلندر بود. ارزیابی‌های میزان گردی و هم مرکزی بوش سیلندر در ۱۲ موقعیت دایره‌ای با فواصل طولی یکسان

صورت گرفت. تعیین تلرانس راستی مورد اندازه گیری نیز در ۵ خط با فواصل طولی یکسان به صورت ۹۰ درجه پیرامون محیط بوش سیلندر صورت گرفت. نتایج حاصل از اندازه گیری ها به منظور بررسی و ارزیابی وضعیت موتور در طول مسیر عملکردی پیستون در درون بوش سیلندر آن مورد بحث، بررسی و تجزیه و تحلیل قرار گرفتند. وضعیت شدت انحرافات پارامترهای مورد مطالعه نشان دهنده وقوع میزان سایش قابل توجه در درون بوش سیلندر بود. به طوری که میزان سایش در مقاطع عرضی در نقاط مرگ بالا و پایین به مراتب بیشتر از میزان سایش صورت گرفته در همان مقطع عرضی در مجاورت نقطه وسط مسیر حرکت پیستون در درون سیلندر و همچنین مقاطع عرضی در مجاورت نقطه مرگ بالا بود. نتایج این بررسی به نوبه خود بازخوردهایی برای طراحان موتور در هنگام اعمال تغییرات مختلف در موتور و هم برای مهندسان نگهداری و تعمیرات به منظور اجرای صحیح نگهداری و تعمیرات پیشگیرانه و پیش‌بینانه را فراهم می‌آورد.

واژه‌های کلیدی: بوش سیلندر، تراکتور، تلرانس‌های هندسی، سایش، فرآیند هونینگ.