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Identification and Mitigation of Machining Process Failures in XE 611 SZK Crankshaft through an Integrated FMEA and Pareto Analysis Approach

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Abstract

The quality of the machining process in critical components such as crankshafts plays a significant role in determining engine performance and reliability. This study aims to analyze the causes of failure in the milling and drilling machining processes of the XE 611 SZK crankshaft. The research methods included direct observation of the production process, analysis of machining parameters, and evaluation of machining quality through visual inspection and dimensional measurements. In addition, root cause analysis was conducted using fishbone diagrams and Failure Mode and Effects Analysis (FMEA) to identify the dominant factors contributing to process failures. Furthermore, Pareto analysis was applied to determine the primary causes of failure based on the 80/20 principle. The results indicate that machining failures were mainly caused by tool wear, improper cutting parameters (cutting speed, feed rate, and depth of cut), machine setup errors, and suboptimal coolant system performance. These failures resulted in surface defects, dimensional deviations, and an increased product rejection rate. The proposed recommendations include optimization of machining parameters, implementation of preventive maintenance for machines and tooling, and enhancement of quality control during the production process. This study is expected to serve as a reference for improving machining efficiency and reducing failure rates in the manufacturing industry.

Keywords: machining, milling, drilling, process failure, product quality

Abstrak

Kualitas proses pemesinan pada komponen kritis seperti poros engkol memainkan peran penting dalam menentukan kinerja dan keandalan mesin. Studi ini bertujuan untuk menganalisis penyebab kegagalan dalam proses pemesinan milling dan drilling pada poros engkol XE 611 SZK. Metode penelitian meliputi observasi langsung proses produksi, analisis parameter pemesinan, dan evaluasi kualitas pemesinan melalui inspeksi visual dan pengukuran dimensi. Selain itu, analisis akar penyebab dilakukan menggunakan diagram tulang ikan dan Analisis Mode Kegagalan dan Dampak (FMEA) untuk mengidentifikasi faktor dominan yang berkontribusi terhadap kegagalan proses. Selanjutnya, analisis Pareto diterapkan untuk menentukan penyebab utama kegagalan berdasarkan prinsip 80/20. Hasil menunjukkan bahwa kegagalan pemesinan terutama disebabkan oleh keausan pahat, parameter pemotongan yang tidak tepat (kecepatan potong, laju umpan, dan kedalaman potong), kesalahan pengaturan mesin, dan kinerja sistem pendingin yang suboptimal. Kegagalan ini mengakibatkan cacat permukaan, penyimpangan dimensi, dan peningkatan tingkat penolakan produk. Rekomendasi yang diajukan mencakup optimasi parameter pemesinan, implementasi perawatan preventif untuk mesin dan peralatan, serta peningkatan kontrol kualitas selama proses produksi. Studi ini diharapkan dapat menjadi referensi untuk meningkatkan efisiensi pemesinan dan mengurangi tingkat kegagalan di industri manufaktur..

Kata kunci: pemesinan, penggilingan, pengeboran, kegagalan proses, kualitas produk.

1. Pendahuluan

Manufacturing is an essential sector in the industrial economy and serves as one of the primary drivers of economic growth. It has been widely recognized as a strategic industry by many countries worldwide, resulting in intense international competition. In particular, the automotive industry in Indonesia plays a significant role in supporting the national manufacturing sector. The production of automotive components requires various supporting tools, commonly referred to as cutting tools, which are essential in machining processes within the automotive industry [1]. One of the vital components in automotive engines is the crankshaft. This component functions to convert the reciprocating motion of the piston into rotational motion, which is then transmitted to the transmission system [2]. To ensure optimal lubrication of moving components, the crankshaft is equipped with oil holes that are produced through a drilling process. During engine operation, problems such as drilling position not good (NG) are frequently encountered in the manufacturing process of the oil holes. Position deviations may cause improper oil flow distribution, reduce lubrication effectiveness, and potentially lead to functional failures in the engine system [3–4]. Therefore, the positional accuracy of drilled holes becomes a critical aspect in the crankshaft manufacturing process. Inspection results revealed variations in hole and milling positions in several crankshaft products that exceeded the allowable tolerance limits. This condition indicates nonconformities in the drilling and milling processes, which may be caused by improper workpiece positioning, inaccurate jig or fixture alignment, cutting tool wear, or instability of the production machine [5]. Based on these issues, it is necessary to conduct an analysis to identify the main causes of milling and drilling position not good (NG) defects in crankshaft oil holes, as well as to propose improvements to the machining process or jig design in order to enhance product quality and minimize production defect rates

2. Metode Penelitian

This research was conducted at PT. Tjokro Morita Gearindo, located at Jalan Rawa Terate 1 No. 9, Pulogadung Industrial Area, East Jakarta, Indonesia. The study was focused on the production division of the camshaft line. Data collection was carried out over approximately five months, from August 11, 2025, to December 23, 2025.

2.1 Research Flow

The research procedure began with a field survey, followed by the identification of the research problem, determination of the supporting theories, data collection, and data processing based on relevant theoretical approaches. The results of the analysis were then used to draw conclusions. The detailed research procedure is illustrated in the flowchart shown in Figure 1

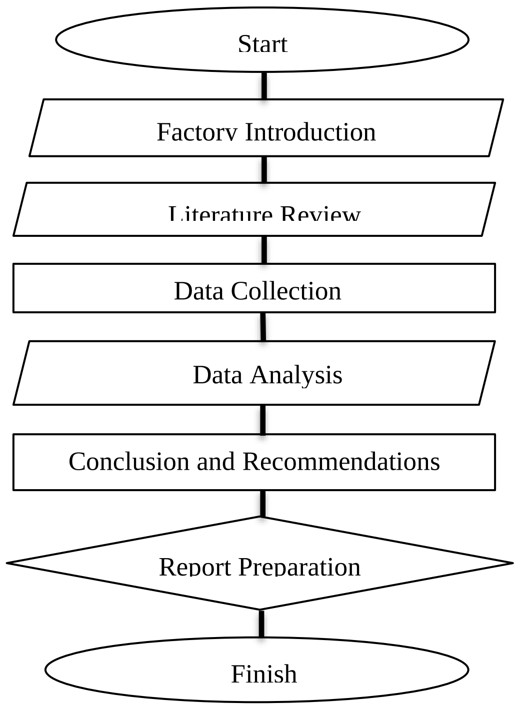

Figure 1. Data Collection Flowchart

3. RESULTS AND DISCUSSION

3.1. Quality Control Data Collection

Quality Control (QC) data collection was conducted during the machining process of XE 611/631 type crankshafts within the period of September 1, 2025, to November 20, 2025. The collected data covered all production stages, including CNC Lathe, Milling, Drilling, Centering, Heat Treatment, and Quality Control processes. The primary focus of the analysis was the 4 mm milling and drilling processes, which repeatedly exhibited Not Good (NG) conditions due to deviations in hole and milling positions exceeding the tolerances specified in the engineering drawings. The results of the QC data collection are presented in Table 1.

4. Table 1. Quality Control Data Collection Results

No	Item NG	May 25	Jun 25	Jul 25	Aug 25	Sep 25	Oct 25	Nov 25	TOTAL	NG (%)
1	Centering (OP1)	1	2	0	0	1	1	0	5	2,28%
2	Lathe (OP 2&3)	2	2	1	3	1	2	0	11	5,02%
3	Drill Position (OP4)	0	0	4	7	4	1	0	16	7,31%
4	Roughboring (OP5)	3	0	4	0	5	0	2	14	6,39%
5	Gun Drill (OP6)	0	3	0	0	0	0	0	6	2,74%
6	Drill Oil Hole (OP7)	0	0	0	0	0	0	1	6	2,74%
7	Rolling (OP8)	0	0	0	0	0	0	0	0	0,00%
8	Chempering (OP9)	0	3	0	4	0	0	1	17	7,76%
9	Grinding (OP10&11)	3	2	0	1	0	3	2	14	6,39%
10	Fine Borring(OP12)	0	3	0	4	3	0	0	10	4,57%
11	Milling & Drilling (OP13)	9	17	9	13	7	18	11	84	38,36%
12	Chip Blow Hole (OP14)	0	1	0	0	0	1	1	6	2,74%
13	Material	1	2	0	0	3	0	9	15	6,85%
14	Rust corrosion	2	3	0	7	0	2	0	15	6,85%
	Total	21	38	18	39	24	28	27	219	

The QC table indicates that production defects were dominated by specific defect types, particularly solder spot defects, which contributed the largest proportion of the total defects. The uneven distribution of defects across the production processes indicates the presence of process variations that require better control. By applying the Pareto approach and scientific analysis, improvement efforts can be focused on the major contributing factors in order to significantly enhance product quality. The NG data of the crankshaft process are presented in the form of a bar chart, as shown in Figure 2.

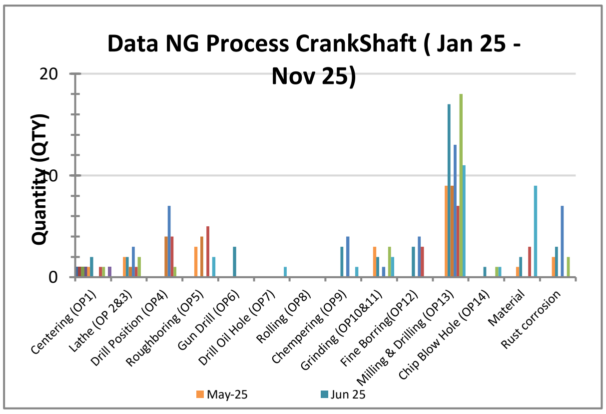

Figure 2. Bar Chart of NG Data in the Crankshaft Process

Based on the bar chart analysis, defects in the crankshaft manufacturing process were predominantly associated with **dimensional defects and circular run-out**, with a significant increasing trend observed during the **October–November**

period. This pattern indicates a strong possibility of process instability related to special cause variation, such as tooling wear, machine misalignment, and degradation in production system performance [3,7,8].

This phenomenon is supported by previous studies stating that dimensional deviations in machining processes are generally caused by tool wear progression and changes in cutting conditions over operating time [4]. Furthermore, a study conducted by **Choudhury and El-Baradie (1998)** demonstrated that tool wear directly increases geometric deviations and surface roughness, thereby contributing to a higher rate of product defects [5]. This finding further strengthens the indication that the increase in NG products during the October–November period was most likely caused by delayed machine maintenance or untimely tooling replacement. In addition, the high variation observed between months indicates that the process had not yet reached a state of statistical control. As explained by Douglas C. Montgomery (2019), significant fluctuations in quality data indicate the presence of assignable causes that must be immediately identified and controlled [9].

From the product quality perspective, defects such as run-out and dimensional deviations in crankshafts are highly critical because they directly affect the dynamic balance and service life of the component. This statement is supported by the study of Gupta and Jain (2014), which explained that geometric nonconformities in rotating components such as crankshafts may lead to vibration, uneven wear, and even premature failure of the engine system [7,8,9,10]. Based on Table 1, the bar chart pattern illustrates the Not Good (NG) findings in the crankshaft machining process during the period from May 2025 to November 2025. The highest NG occurrence was observed in the Milling & Drilling process, showing an increase of more than 15 cases in certain months. From the data visualization, it can be concluded that the primary focus of quality improvement should be directed toward the Milling & Drilling processes, as well as several supporting processes that consistently exhibited high NG values. By analyzing and improving these dominant processes, a significant reduction in NG rates can be achieved, thereby improving the overall quality of the crankshaft product.

3.2 Pareto Chart of Crankshaft NG Data

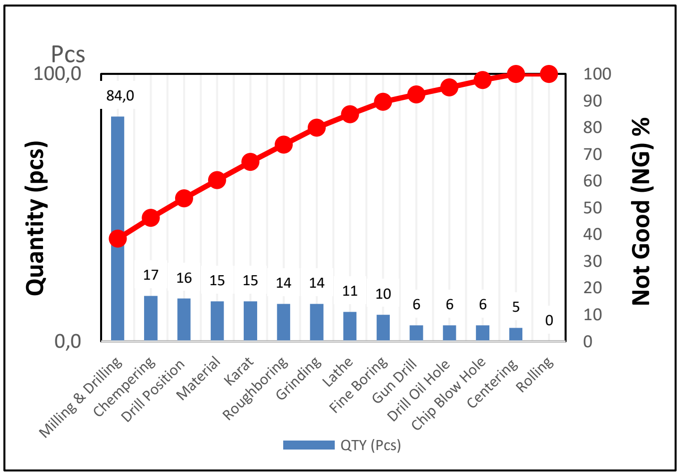

Figure 3. Pareto Diagram of Crankshaft NG Data

The Pareto diagram shown in Figure 3 presents the distribution of defect types (NG) in the crankshaft manufacturing process during the period of May 25 to November 25. The data are illustrated using bar charts representing the quantity of defects (QTY pcs) and a cumulative percentage curve (% cumulative). The purpose of this analysis is to identify the major sources of NG defects so that improvement efforts can be focused on the most significant causes. By understanding the NG distribution pattern presented in the diagram, corrective actions can be implemented more effectively, systematically, and accurately targeted. The Pareto chart indicates that the majority of defects in the crankshaft process originated from several dominant causes, particularly drilling process failures and dimensional deviations. The top five defect categories contributed to most of the total defects, indicating that improvement efforts should be concentrated on these factors in order to achieve significant quality enhancement. This approach is consistent with the Pareto principle and modern quality control theories, which emphasize prioritizing the vital few rather than the trivial many [11,12].

Overall, the results of this study demonstrate that the combination of QC analysis, trend diagrams, and Pareto analysis constitutes an effective approach for identifying the root causes of quality problems in the crankshaft manufacturing process. The dominance of defects in the drilling process and dimensional deviations indicates that improvement efforts should be focused on critical process points in order to achieve significant and sustainable quality improvement [5,13].

3.3 Failure Analysis in the Milling & Drilling Process

Based on the data collected from the milling and drilling machining line during the May–November period, the most dominant NG types and the number of defective parts are presented in Table 2.

Table 2. Types of Failures in the Milling & Drilling Process

No	Types of NG (Non-Good)	QTY
1	Hole diameter out of tolerance (oversize/undersize)	35
2	Hole position shifted from the center axis.	21
3	Chamfer and finishing inaccuracies due to changes in the reference point.	11
4	Ovality / diameter asymmetry.	17
	Total	84

Table 2 shows that failures in the milling and drilling processes were predominantly caused by dimensional defects and hole position deviations, which are directly related to tool condition, machining process stability, and the accuracy of the production system [8,14]. With more than 60% of the defects originating from dimensional factors, improvement strategies should be focused on process parameter control and tool management in order to achieve significant quality enhancement.

The graph of failure types in the milling and drilling processes is presented in Figure 4.

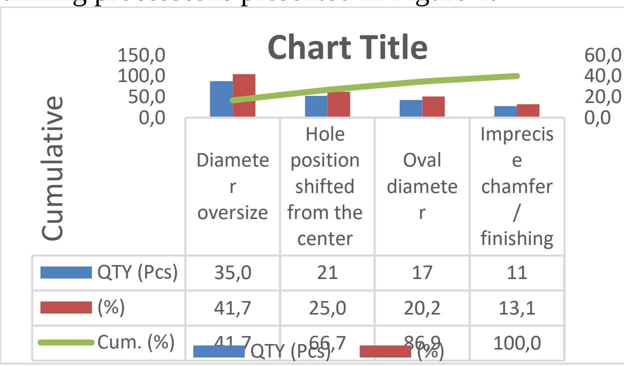

Figure 4. Types of Failures in the Milling & Drilling Process

Based on the Pareto diagram, the types of failures occurring in the milling and drilling processes can be explained as follows [13,14]:

- **Diameter oversize**, where the machined diameter exceeds the tolerance specified in the process sheet.
- **Hole position shifted from the center**, causing asymmetry and interfering with the functionality of subsequent assembly processes.
- **Oval diameter**, where the hole geometry does not meet the required specifications, resulting in insufficient part precision.
- **Imprecise chamfer/finishing**, causing the chamfer section to become uneven, less symmetrical, or excessively deep. Although this case occurred less frequently, it remained significant.

Based on the NG data collected from the machining process during the May–November period, an increasing trend of Not Good (NG) products was identified, particularly in the milling and drilling processes. Most of the NG cases showed a consistent pattern of deviation. Furthermore, based on crankshaft inspections using a Coordinate Measuring Machine (CMM), the results from three CMM reports (No.01, No.02, and No.03) indicated that several symmetry parameters exceeded the specified tolerance limits, as shown in Figure 5.

Failures in the milling and drilling processes are the result of complex interactions among human, machine, method, material, measurement, and environmental factors. Dominant factors such as tool wear, non-optimal process parameters, and system misalignment were identified as the primary causes of dimensional and geometric defects [8]. Therefore, a data-driven approach and systematic process control are essential to improve product quality and consistency [9,15].

Based on Figure 5, the CMM inspection results indicate the presence of asymmetry defects. These asymmetry deviations generally occurred in the parameters **Symmetry CIR1/PLN2 – P-Zone** (milling) and **Symmetry CIR1/PLN3 – P-Zone** (drilling This asymmetry indicates that the geometric positions of the milling and drilling features were not precisely centered or properly aligned with the reference datum specified in the engineering drawing. As a result, the material removal process occurred under conditions where the workpiece was not perfectly centered during machining operations [10]. Based on the results of the physical inspection of the jig and re-measurement using a bore gauge, the diameter of the jig bushing/locator, which determines the crankshaft position, can be observed as shown in Figure 6.

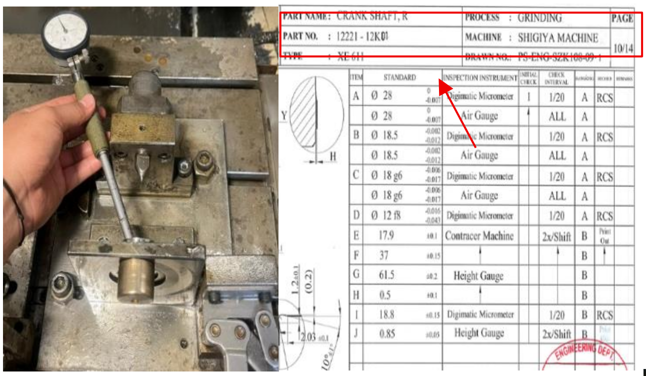

Figure 6. Inspection of Jig Bushing Condition

The measurement results obtained using a bore gauge and compared with the engineering drawing specifications and required tolerance revealed that: (1) the jig diameter experienced an oversize condition with a measured value of 29.678 mm, exceeding the specified design tolerance of $\emptyset 28^{0}_{-0.007}$. As a result of the oversize condition, the crankshaft could not be clamped precisely. Furthermore, (2) a clearance gap was formed, which potentially caused workpiece looseness and instability during the machining process, and (3) the locator experienced wear due to long-term usage.
Figure 6 illustrates the inspection process of the jig bushing, which is a critical component in maintaining drilling process accuracy. Wear or dimensional nonconformity in the bushing can become a major cause of dimensional and geometric defects such as oversize, misalignment, and ovality. Therefore, controlling bushing conditions through routine inspections and monitoring systems is essential to maintain process stability and product quality [10,13,15]. The oversize condition of the jig was identified as the main cause of positional deviations during the milling and drilling processes. The inspection results of the locator jig condition are presented in Figure 7. The measurement results showed that the locator jig diameter was 29.691 mm, whereas the specification in the process sheet was Ø29.880 ± 0.1. This indicates that the locator jig was in an undersize condition (-0.189 mm). Consequently, the locator jig was unable to hold the crankshaft properly during machining operations. This condition triggered positional shifts, resulting in NG products. Furthermore, the roughness inspection conducted to ensure that the surface quality of the crankshaft after the grinding machining process met the required standards is shown in Figure 8.

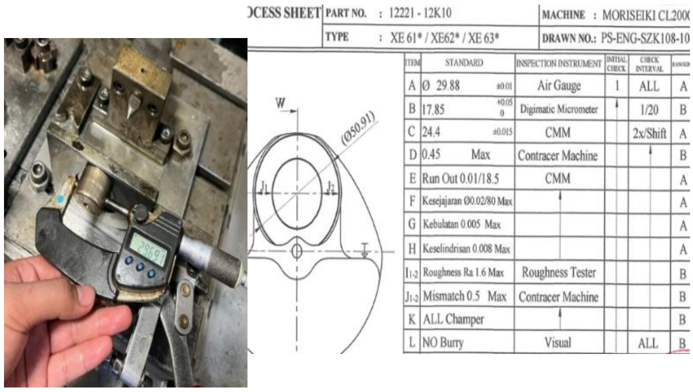

Figure 7. Measurement of the Locator Jig

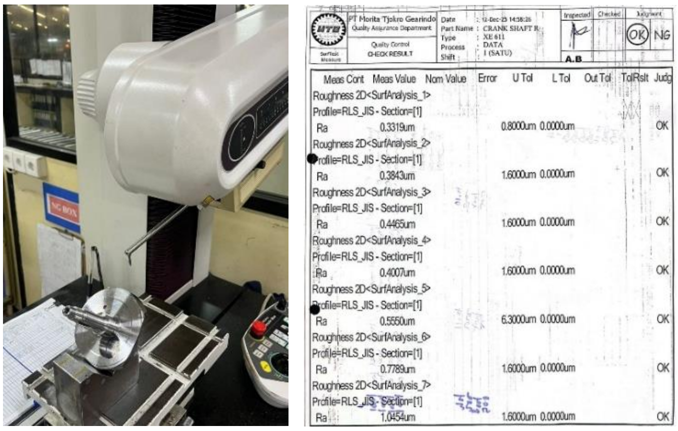

Figure 8. Roughness Inspection Results

All measured Ra values remained below the maximum tolerance limit, indicating that no values exceeded the upper tolerance and no out-of-tolerance conditions occurred. These results demonstrate variations in surface roughness among the measurement points, which are still considered acceptable due to differences in measurement positions and the machining/grinding tool process conditions [11].

4. CONCLUSION

Based on the results of data collection, measurements, and failure analysis conducted during the milling and drilling processes of the XE 611 SZK crankshaft, it can be concluded that the non-good (NG) product failures were predominantly caused by issues related to the clamping system and the workpiece positioning reference. Inspection results indicated that the jig used in the process had become loose or oversized, resulting in inaccurate positioning of the crankshaft during the milling and drilling operations.

This positional inaccuracy caused dimensional deviations, particularly in the drilled holes, which exhibited axis displacement (offset), asymmetry, and nonconformity with the specified diameter standards. These findings were further supported by inspection results obtained using measuring instruments such as the Coordinate Measuring Machine (CMM), digimatic micrometer, and other supporting measurement tools, which indicated values exceeding the standard tolerance limits.

In addition, the failures were also influenced by several supporting factors, such as jig wear due to long-term usage, insufficient periodic monitoring of jig conditions, and the suboptimal implementation of preventive inspection systems prior to the machining process. As a result of these combined factors, the quality of the crankshaft became inconsistent and potentially caused issues in subsequent manufacturing processes as well as during assembly operations.

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