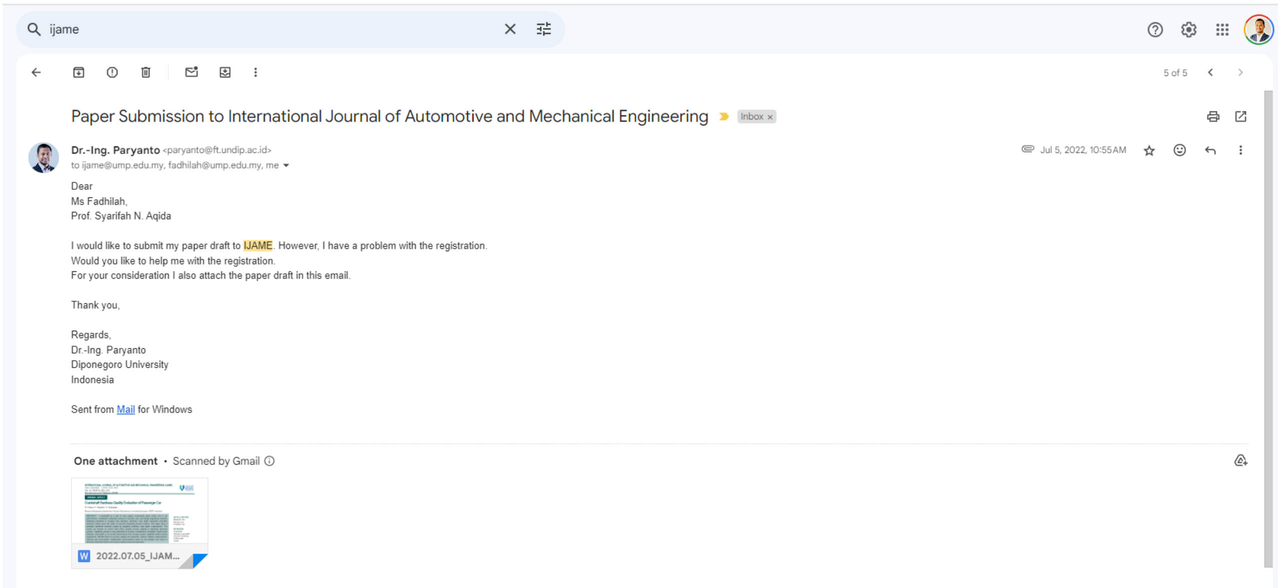
Bukti Korespondensi

Penulis : **Paryanto** (*corresponding author and 2nd author*)
Jurnal : ***International Journal of Automotive and Mechanical Engineering (IJAME)*** – Published by University Malaysia Pahang Publishing **(Q3) – SJR 2023: 0,27**
Judul Paper : *Crankshaft Hardness Quality Evaluation of Passenger Car*

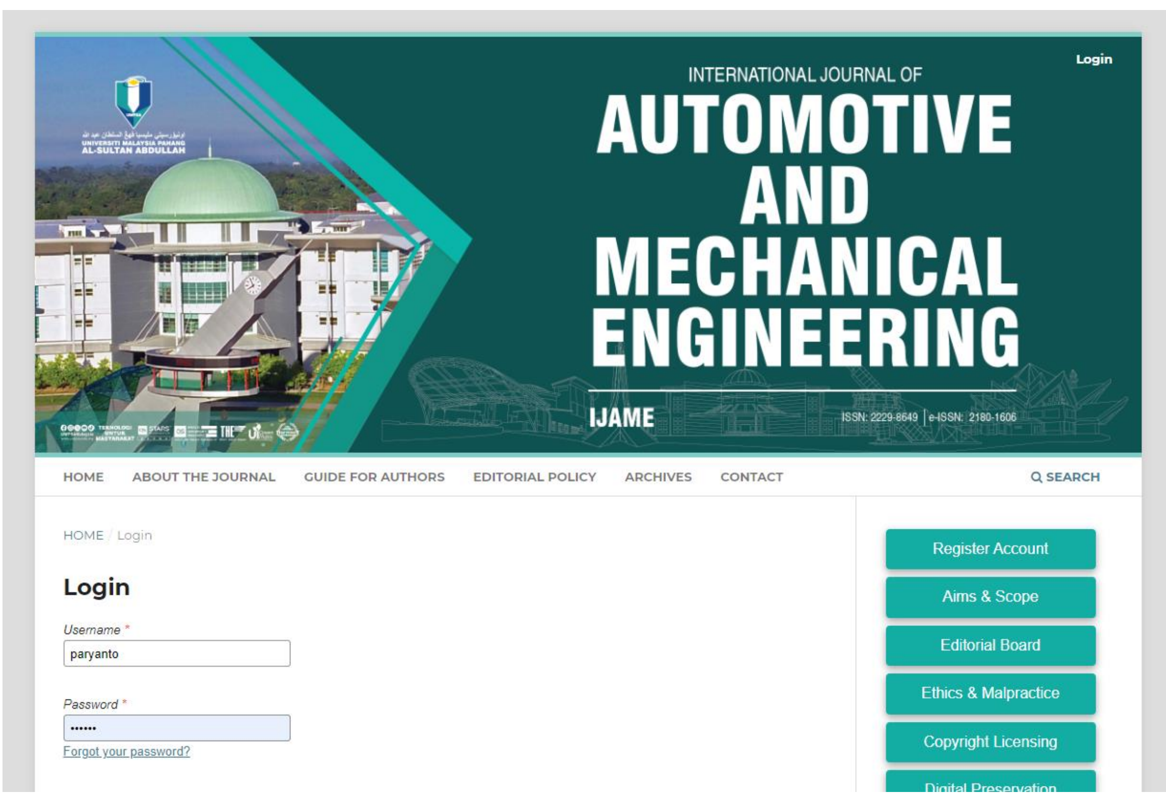
No	Jenis Korespondensi / Kegiatan	Tanggal	Lampiran bukti
1	Paper registration and submission	Jul 5, 2022	Lampiran 1
2	Paper registration and submission via portal submission	Jul 2, 2022	Lampiran 2
3	Editor decision: need for revision	Sep 20, 2022	Lampiran 3
4	Revision submitted (R1)	Sep 29, 2022	Lampiran 4
5	Editor decision: Revision no. 2 and copyright agreement	Sep 30, 2022	Lampiran 5
6	Revision submitted (R2)	Oct 04, 2022	Lampiran 6
7	Editor decision: accepted	Oct 07, 2022	Lampiran 7
8	English proofreading	Dec 13, 2022	Lampiran 8
9	Paper published	Mei 09, 2023	Lampiran 9

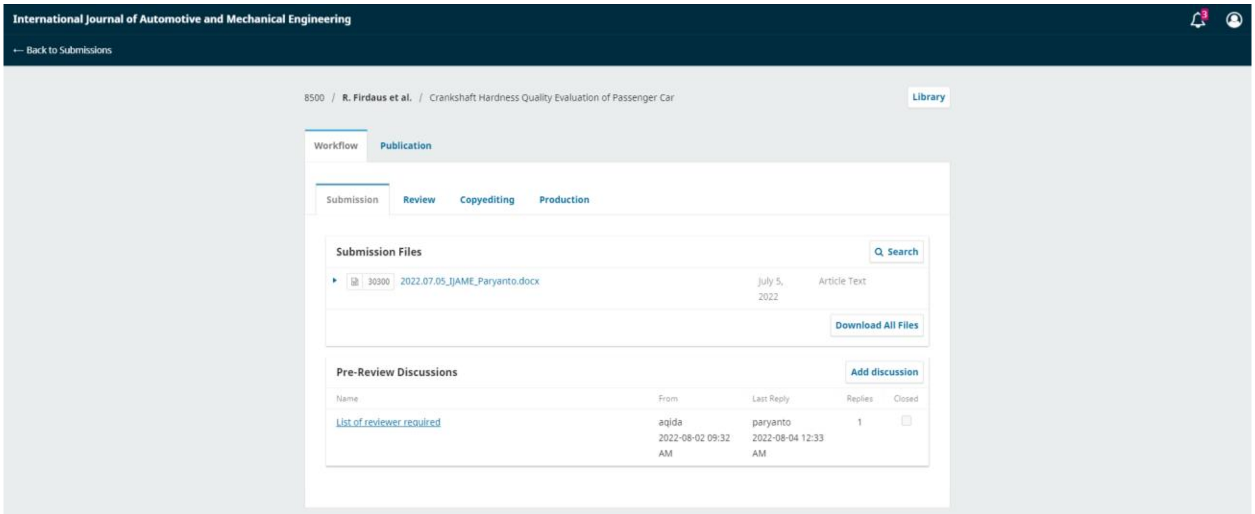
Semarang, 07.2024

Lampiran 1: Pre-Paper registration and submission

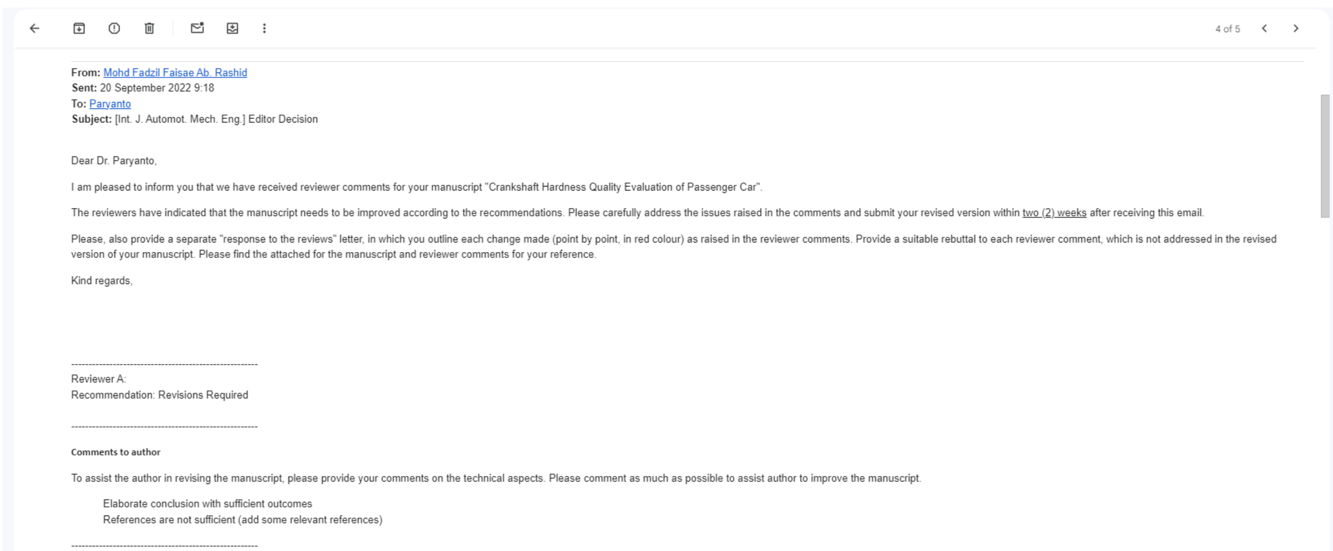


Lampiran 2: Paper registration and submission via portal submission





Lampiran 3: Editor decision: need for revision



4 of 5

From: Mohd Fadzil Faisae Ab. Rashid
Sent: 20 September 2022 9:18
To: Paryanto
Subject: [Int. J. Automot. Mech. Eng.] Editor Decision

Dear Dr. Paryanto,

I am pleased to inform you that we have received reviewer comments for your manuscript "Crankshaft Hardness Quality Evaluation of Passenger Car".

The reviewers have indicated that the manuscript needs to be improved according to the recommendations. Please carefully address the issues raised in the comments and submit your revised version within two (2) weeks after receiving this email.

Please, also provide a separate "response to the reviews" letter, in which you outline each change made (point by point, in red colour) as raised in the reviewer comments. Provide a suitable rebuttal to each reviewer comment, which is not addressed in the revised version of your manuscript. Please find the attached for the manuscript and reviewer comments for your reference.

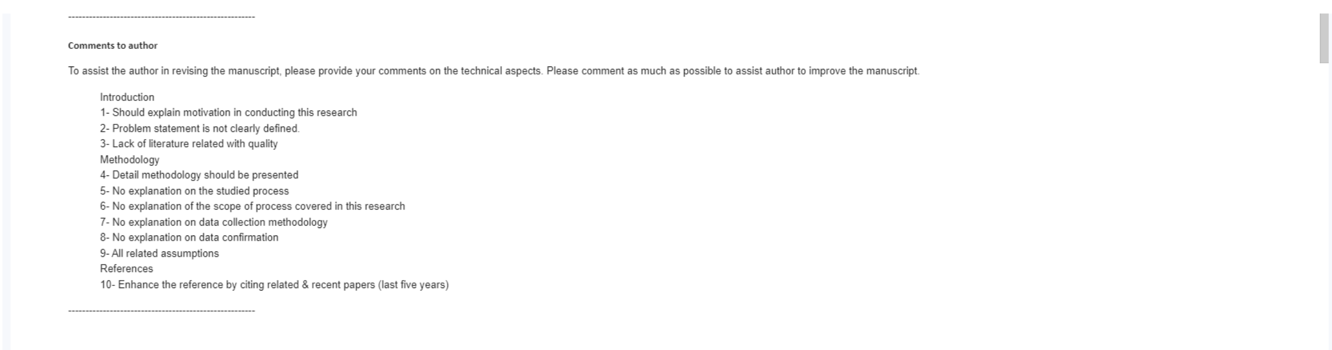
Kind regards,

Reviewer A:
Recommendation: Revisions Required

Comments to author

To assist the author in revising the manuscript, please provide your comments on the technical aspects. Please comment as much as possible to assist author to improve the manuscript.

Elaborate conclusion with sufficient outcomes
References are not sufficient (add some relevant references)



Comments to author

To assist the author in revising the manuscript, please provide your comments on the technical aspects. Please comment as much as possible to assist author to improve the manuscript.

Introduction
1- Should explain motivation in conducting this research
2- Problem statement is not clearly defined.
3- Lack of literature related with quality
Methodology
4- Detail methodology should be presented
5- No explanation on the studied process
6- No explanation of the scope of process covered in this research
7- No explanation on data collection methodology
8- No explanation on data confirmation
9- All related assumptions
References
10- Enhance the reference by citing related & recent papers (last five years)

Lampiran 4: Revision submitted

Dr.-Ing. Paryanto <paryanto@ft.undip.ac.id> Sep 29, 2022, 5:24 PM
to Mohd, me, arsip.paryanto@gmail.com

Dear Prof. Dr. Faisae ab Rashid,

After very deep considering the remarks and suggestions from reviwer. We already revise the draft, which can be found in the attached file.
In the new draft we revise with:

- More explanation of the research motivation and background.
- Improving the literature review with the most recent papers.
- More detailing in research methodology and results
- Improving the grammars and spelling

(all of our revisions are traced using MS Word "Track Changes")

We hope that our revisited paper full fill the Journal criteria. Thank you for your consideration.

Best regards,
Paryanto
paryanto@ft.undip.ac.id

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One attachment • Scanned by Gmail

2022.09.29_IJAM...

Lampiran 5: Editor decision: Revision no. 2 and copyright agreement

From: ijame3 .
Sent: 30 September 2022 10:10
To: Dr.-Ing. Paryanto
Subject: Re: [Int. J. Automot. Mech. Eng.] Editor Decision

Dear Dr. Ing. Paryanto,

Thank you for the revised manuscript. In addition to the revised manuscript, please send the following documents:
1. A separate Response to Reviewers' comments.
2. Copyright transfer agreement as attached.
3. Clearly indicate in the revised manuscript which changes have been made for each comment (by highlighting/comment in manuscript).
Thank you. Regards.

3 Attachments • Scanned by Gmail

2022.10.04_IJAM... | Copyright Transf... | Response to Revi...

Reply | Reply all | Forward

Lampiran 6: Revision submitted no. 2

Dr.-Ing. Paryanto <paryanto@ft.undip.ac.id>
to ijame3, me, arsip.paryanto@gmail.com

Dear Prof. Faisae

Following are the documents that requested by the IJAME (please find in the attached file).
Thank you.

Regards,
Paryanto

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Lampiran 7: Editorial decision: Accepted

From: Mohd Fadzil Faisae Ab. Rashid
Sent: 06 October 2022 13:39
To: Paryanto
Subject: [Int. J. Automot. Mech. Eng.] Editor Decision

Dear Dr. Paryanto:

We have reached a decision regarding your submission to International Journal of Automotive and Mechanical Engineering, "Crankshaft Hardness Quality Evaluation of Passenger Car".

Our decision is to: Accept Submission

International Journal of Automotive and Mechanical Engineering (IJAME)
http://journal.ump.edu.my/ijame

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If printing is necessary, please print it on both sides."

Universiti Malaysia Pahang

Received, thank you. | Got it, thanks! | Thanks a lot.

Lampiran 8: English proofreading

2 of 5

RE: [Int. J. Automot. Mech. Eng.] New notification from International Journal of Automotive and Mechanical Engineering Inbox

Dr.-Ing. Paryanto <paryanto@ft.undip.ac.id> Tue, Dec 13, 2022, 2:22 PM
to Syarifah, me, Mohd, arsip.paryanto@gmail.com

Dear Prof. Aqida,

Please find the draft that was proofed by an English proofreading services. I hope that the draft fulfill the Journal requirements.
Thank you.

Regards,
Paryanto

Sent from Mail for Windows

From: S.N. Aqida
Sent: 10 December 2022 20:46
To: Paryanto
Subject: [Int. J. Automot. Mech. Eng.] New notification from International Journal of Automotive and Mechanical Engineering

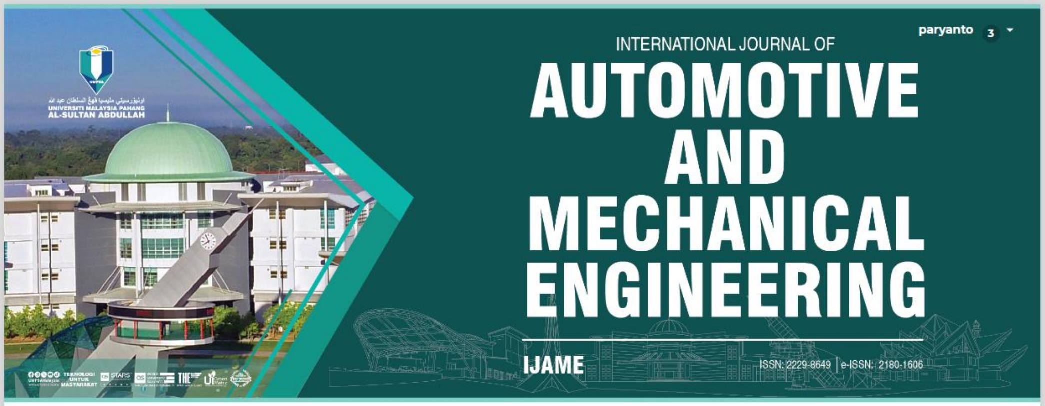
You have a new notification from International Journal of Automotive and Mechanical Engineering:

You have been added to a discussion titled "English proofreading required" regarding the submission "Crankshaft Hardness Quality Evaluation of Passenger Car".

Link: https://journal.ump.edu.my/ijame/authorDashboard/submission/8500

International Journal of Automotive and Mechanical Engineering (IJAME)
http://journal.ump.edu.my/ijame

Lampiran 9: Paper published



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Crankshaft Hardness Quality Evaluation of Passenger Car

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DOI: https://doi.org/10.15282/ijame.20.1.2023.13.0798

Keywords: Crankshaft, Hardness case depth, Induction hardening, Control chart, Quality

ABSTRACT

A crankshaft is a part of the main engine components and plays a critical role in car performance. The crankshaft component consists of journals, pins, and flange that experience induction hardening treatment to increase their hardness. Hardness case depth represents important hardness criteria achieved by the depth of induction hardening process. This paper aims to evaluate crankshaft hardness quality by analyzing hardness case depth measurement. The control chart shows the results, which presents process stability to indicate abnormal processes. The capability process is also performed to process consideration. Evaluation results show hardness case depth is not at its best performance even though process capability meets product requirements. Affected factors to process stability are manpower, method, material, measurement, machine and environment. Implemented improvements based on the problem root cause to eliminate influenced factors and achieve stable process are delivered.

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ORIGINAL ARTICLE

Crankshaft Hardness Quality Evaluation of Passenger Car

R. Firdaus, P. Paryanto* and S. Sulardjaka

Mechanical Engineering Department, Faculty of Engineering, Universitas Diponegoro, 50275, Indonesia

ABSTRACT – A crankshaft is a part of the main engine components and plays a critical role in car performance. The crankshaft component consists of journals, pins, and flange that experience induction hardening treatment to increase their hardness. Hardness case depth represents important hardness criteria achieved by the depth of induction hardening process. This paper aims to evaluate crankshaft hardness quality by analyzing hardness case depth measurement. The control chart shows the results, which presents process stability to indicate abnormal processes. The capability process is also performed to process consideration. Evaluation results show hardness case depth is not at its best performance even though process capability meets product requirements. Affected factors to process stability are manpower, method, material, measurement, machine and environment. Implemented improvements based on the problem root cause to eliminate influenced factors and achieve stable process are delivered.

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KEYWORDS
Crankshaft;
Hardness case depth;
Induction hardening;
Control chart;
Quality

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ORIGINAL ARTICLE

Crankshaft Hardness Quality Evaluation of Passenger Car

R. Firdaus, P. Paryanto*, S. Sulardjaka

Mechanical Engineering Department, Faculty of Engineering, Universitas Diponegoro, 50275, Indonesia.

ABSTRACT – Crankshaft as a part of main engine components plays critical role to car performance. Crankshaft component consists of journals, pins, and flange experience induction hardening treatment to increase their hardness. Hardness case depth represents important hardness criteria which the depth of induction hardening process achieve. This paper aims to evaluate crankshaft hardness quality by analyzing hardness case depth measurement. The results are showed by control chart which present process stability to identicate abnormal process. Capability process is also performed to process consideration. Evaluation results show hardness case depth is not at best performance even though process capability meets product requirement. Affected factors to process stability are manpower, method, material, measurement, machine and environment. Implemented improvements based on the problem root cause to eliminate influenced factors and achieve stable process are delivered.

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Accepted: xxxx

KEYWORDS
Crankshaft;
Hardness case depth;
Induction hardening;
Control chart;
Quality.

INTRODUCTION

Engine is main vehicle powertrain consist of five main components that are crankshaft, cylinder block, cylinder head, camshaft and connecting rod. Crankshaft is the most important rotary component that plays critical role to car performance. Crankshaft failure will not affect to the crankshaft itself but also other engine components including the cylinder block, connecting rods, pistons and bearings [1]. –Crankshaft is transforming energy through converting reciprocateidve motion to rotational motion as impact of thermal expansion inside cylinder head [2]. Crankshaft component consists of journal, pin, flange and counterweight. Journal will be installed to cylinder block, pin is assembled with connecting rod, flange is as flywheel counterpart and counterweight works to balance the crankshaft by compensating centrifugal force from rotational move [3].

Crankshaft is manufactured in machining line that is dominated by turning and milling process. Besides that, machining line provides hardening treatment by induction hardening process. Hardening treatment proposes to increase crankshaft hardness as one of mechanical properties major. Mechanical properties affect mechanical strength level and material ability to be formed. Mechanical properties show material capability to resist against mechanical load [4]. Mechanical properties are identified for material standardization or design need. In general, some off mechanical properties such as strength, toughness and hardness are measured after raw material forming becomes finish product. Material hardness is one of mechanical properties that show material resistance against plastic deformation by other material. [5]. Crankshaft especially journal, pin and flange should meet minimum criteria of hardness value to present best performance and guarantee meyendworking failure resistance.

Any process that increase hardness layer level is called as surface hardening treatment. Formed hardness layer by surface hardening treatment is called as case that has various depth in range between 0.0025 to 10 mm [6]. Hardness case depth term is stated to describe the depth of formed hardness layer after surface hardening process. Induction hardening treatment is common method used to increase surface and component layer hardness of material. During induction hardening treatment, material microstructure of surface and layer are transforming become more compressive [7]. Journal, pin and flange component are hardened by induction hardening process. The treatment guarantee journal, pin and flange resist of working failure such as crack. Furthermore, friction force reveals between journal and cylinder block assembly and pin and connecting rod assembly increase wear possibility. Journal and pin should have higher hardness than counterpart to prevent excessive wear [3].

Induction hardening treatment is usually used to increase surface hardness of medium carbon steel. Surface hardening is conducted using high frequency induction coil to fasten the heat treatment time. Frequency level of induction coil depends on desirable case depth. Heat treatment causes material microstructure to form austenit then followed by quenching and tempering process to complete the process and release residual stress [5]. Induction hardening treatment that is used in machining line consist of three different induction coil for journal, pin and flange component. Induction hardening treatment starts from journal 1 and pin 1, journal 2 and pin 2, journal 3 and pin 3 and last journal 4 and flange consecutively.

Hardness becomes one of important point aspects to control. Hardness case depth is a part of hardness criteria that contributes to wear and crack failure potential [8]. Hardness case depth is perpendicular distance from hardened surface to the deepest point of hardness layer or in other word, it is criteria that shows how deep the hardness treatment achieve.

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There are two kinds of hardness case depth, total case depth and effective case depth. Total case depth describes hardness depth perpendicularly from surface layer where hardness value does not decrease and stay on stable condition due to achieved hardness peak. Total case depth shows the depth condition that carbon composition reach 0.04% more than core carbon. Effective case depth explain the depth and area that have hardness Vickers value equal to 550 by 9.81 Newton load [9]. It can be said also where hardeness depth reaches HRC 45 minimally. Less hardness value will contributes to overall hardness quality and decrease crankshaft durability against fatigue. Small crack could be a sign as the impact.

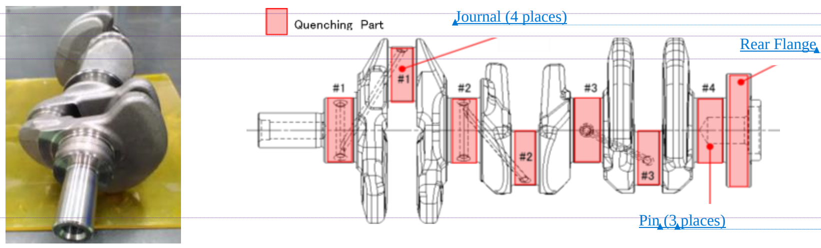
Various researchs show the importance of case depth regarding surface hardness crankshaft. Xu and Yu [10] conduct failure analysis of a truck diesel engine crankshaft and found the occurred crack is taken place on lower surface hardness part component area. Component area with corresponded hardness case depth is tougher than other area. Fonte et all [11] explain partial absence of surface hardening layer decrease fatigue strength and wear resistance of diesel cranksahft. Crack initiation appear in weaker region and lead to fatigue. Fonte et all [12] shows severe hardening also could contribute to initial crack. Surface hardening by an adequate heat treatment are recommended for better quality of crankshafts. Witek et all [13] found ununiform surface hardening process accelerate crack initiation in diesel engine crankshaft pin. Large hardness is concetrated in the center so edge area is much smaller.

Hardness case depth is controlled by two inspection methods are Non-Destructive Test (NDT) by using hard echo ultrasonic wave and Destructive Test (DT) through direct measurement using micro Vickers by cutting the crankshaft into pieces. Hard echo is used frequently due to its function as quick measurement for quick judgment. Hardness case depth faces unachieved minimum hardness concern which occur several times. Due to its failure potential if hardness case depth do not achieve minimun value, Tthe concern needs more attention to find the problem root cause and perform countermeasure immediately. This research aims to evaluate crankshaft hardness case depth to measure quality level, and find the root cause of hardness case depth value instability. Beside enriching reference to limited research about crankshaft hardness case depth, this research will reveal factors related process instability, and conduct provide appropriate countermeasure to tackle the concerns and suggest preventive actions to do. .

METHODOLOGY

Material

The crankshaft which evaluated in this research is passanger car type. The crankshaft material is forged metal that formed by forging process at raw material supplier. The crankshaft is three cylinder model that propose to 1200 cc engine capacity as shown in Figure 1. Crankshaft is hardened by induction hardening process. Hardening process is conducted in the middle stage of machining process. Raw material crankshaft will be pre-machined on front shaf, journals, pin and flange area. Each component of journal, pin and flange area then experience induction hardening process. Induction hardening treatment that is used in machining line consist of three different induction coil for journal, pin and flange component. Induction hardening treatment starts from processing journal 1 and pin 1, journal 2 and pin 2, journal 3 and pin 3 and last journal 4 and flange consecutively.



(a) Crankshaft (b) Hardening area

Figure 1. Three cylinder crankshaft model.

Data Collection and Process

Data used in this research is gathered from routine measurement data for one year. Data is measured from crankshaft that finish induction hardening process with focus on hardness case depth point only. Hardness case depth is measurement point of induction hardening process that faces unachieved minimum value concern. Hardness case depth is measured one per shift at the beginning shift to determine the cranskhaft hardness quality of the production day can go or not. Data processing is started by preparing the data. Data is analyzed by using control chat method to visualize process condition. Calculation is conducted to find process stability and capability. Sensitivity analysis is used to recognize abnormal point which represents abnormal process. Each abnormal point is mapped into six factors by using cause and effect diagram. Every factor then analyzed deeper by using five whys analysis to find the root cause as shown in Figure 2.

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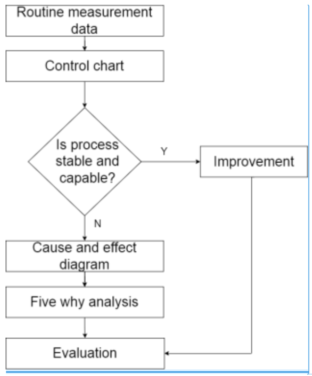

Figure 2. Data processing methodology.

Measurement Process

Quality control is an activity carried out to measure the actual performance of an ongoing process, compare actual performance with predetermined criteria, and take corrective action if deviations occur. Quality control is a system that aims to create products that meet consumer needs. So that quality control is an effort made to ensure that the products produced meet the established criteria. Quality is one of major element of operation planning in manufacturing industries [18]. ~~So that quality control is an effort made to ensure that the products produced meet the established criteria.~~ Quality is also defined as the suitability of use which consists of two aspects, namely quality of conformance and quality of design [~~10~~][20]. Quality of conformance aspect related to product quality with specifications and tolerances are determined through factors such as the selection of manufacturing processes. The quality of design aspect refers to variations in the design of a product such as variations in type, size, appearance, and performance. These variations lead to differences in the manufacturing process as well as the tools and machines used.

Quality control begins with the process of identifying the main criteria that can meet customer wants and needs. The process is continued by designing product features from the main criteria, designing processes for making these features to controlling the feature creation process. Offline quality control includes assessment of consumer needs and desires, product characteristic design and manufacturing process design, while online quality control is carried out during the ongoing process through ongoing process control. Product sampling is one of the main factors in controlling and improving product quality. Sampling inspection is closely related to product inspection, which is the earliest quality control method in which statistical quality control is not widely used.

Measurement holds important role to guarantee product quality. Hardness case depth measurement is conducted once per shift by using hard echo ultrasonic wave namely ha~~a~~rd echo as shown in Figure 3~~1~~. Measurement results determine required action to keep quality at desirable level such as machine setting, maintenance, countermeasure and problem-solving. Trained quality assurance operators measure the crankshaft at beginning of shift.

Hardness case depth is controlled by two inspection methods are Non-Destructive Test (NDT) by using hard echo ultrasonic wave and Destructive Test (DT) through direct measurement using micro Vickers by cutting the crankshaft into pieces. Hard echo is used frequently due to its function as quick measurement for quick judgment. Ultrasonic measurement is widely used today due to rapid technology development and part integrity issue. Beside ultrasonic wave measurement for hardness case depth, there are various research related Non-Destructive Measurement. Mao et all [14] use nonlinear ultrasonic for carburized case depth measurement. Satoru et all choose [15] magnetic hysteresis technology for case depth measurement on induction hardened steel rods research. Send et all [16] use low frequency magnetic field measurement or Barkhausen noise method for case hardening depth measurement. Schneider et all [17] use laser ultrasonic detection method or surface acoustic wave for hardened steel hardness depth measurement.

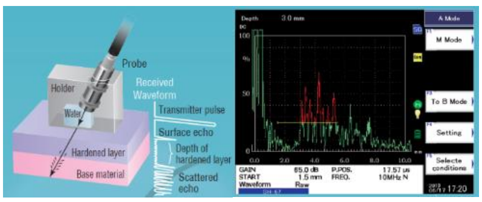

Figure 3~~1~~. Measurement process.

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Ultrasonic wave of hard echo is obtained by measuring propagation wave time between sensor and transition zone. Measurement principal of hard echo is identifiying hardened layer characteristic. Hardened layer has finer microstructure than non-hardened layer. Ultrasonic wave propagate through hardened layer and base layer then create scatter as result.

Measurement result will be used to create control chart, process stability measurement and process capability measurement. There are eight parts of crankshaft hardness depth case measurement result which consist of four journal components, three pin component and one flange component, so the control chart. At the end, control chart of four journal components will be combined as one control chart named journal, so the control chart of pin. Process stability and capability consist of three component group named as journal, pin and journal. The data will be calculated uses Minitab 19.

Control Chart

Quality is related to variability. A product has good quality if contains less variability. Product sampling technique is related to product inspection when quality control is known and statistic method has not widely developed. Current quality control does not emphasize product sampling as main method and focus more on statistical process control and experimental design. Product sampling shows quality as only as conformance to specifications but does not provide feedback on the manufacturing process, design or product development that could lead to quality improvment. Quality improvement has the primary objective of reducing variability in important product characteristics. In the early stages of quality control development, product sampling is used as the primary tool with out-of-spec products dominating the output process. However, statistical process control development could stabilize the process in such a way to reduce variability.

Statistical process control is a method that aims to obtain stability and improve process capability using statistical techniques to reduce variability [10][20]. Control chart is a part of statistical process control to identify working process. Control chart is able to show process abnormality to analyze. Each process abnormality will be checked to figure out the abnormal event happened at the time. Every event will be classified into common cause and special cause. Common cause comes from natural variability of the process so it is ignored. Even with good process design and machine maintenance, natural variability is inevitable in any production process. Natural variability is a collection of small things that are impossible to avoid. A process that works only with variations due to a common cause is called a statistically controllable process. Another variability that can occur in the production process is special cause. Special cause is variability comes from external factors such as machine error, human mistake and inconsistent material composition.

Control chart shows the process stability which restricted by control limit which defined based on its process variability. Control limit usually provides more strict criteria than specification limit so it can prevent the product result exceeds the standard and goes to defect product. Specification limit is a criterion determined by the company based on the suitability of the function of a product. If the product is outside the specification limit, the product can be said to be Not Good (NG), but if the product is outside the control limit, the product can still be said to be good but the process is experiencing instability, so it is necessary to find the cause and make improvements to prevent more severe instability causing instability. product out of specification limit. The cause of this variability has an impact on the process variability which is very large when compared to the common cause. A process that occurs with a special cause in it is called an uncontrolled process.

Control chart has the main function of detecting special causes that lead to process deviations early [19]. This allows decision makers to investigate processes and take corrective action before deviations from production standards occur. The goal to be achieved by the control chart is to eliminate process variability, although variability cannot be completely eliminated because there are always undesirable factors that exist naturally. The control chart was developed to reduce variability as much as possible in the hope that the process can be maintained stable.

Statistical methods have an important role in efforts to improve and improve quality because the variability that occurs in the process can only be explained through statistical terms [20]. There are two classifications of data on quality control, namely attribute data and variable data. Attribute data is discrete data that is commonly used to evaluate processes based on product defects, while variable data is continuous measurement data that is commonly used to evaluate processes through product parameter measurements. In addition, there are two types of control charts, namely variable control charts and attribute control charts. Each of control chart plays a role in controlling quality based on the type of data applicable to the product.

This research uses EWMA (Exponentially Weighted Moving Average) control chart type due to its ability to proceed non normal distribution data. EWMA is kind of special variable control chart. EWMA is a control chart that calculates a weighted average from the results of observations that have been carried out previously and also currently so that this control chart is not sensitive to the issue of normality [10][20]. EWMA creates control chart by using one sample for each observation which meets measurement method used in the production line. The EWMA is shown as z formula is given as follows,

$$z_i = \lambda x_i + (1 - \lambda) z_{i-1} \tag{1}$$

$$UCL = \mu_0 + L\sigma\sqrt{\frac{\lambda}{2-\lambda}[1-(1-\lambda)^{2i}]} \tag{2}$$

$$CL = \mu_0 \tag{3}$$

$$LCL = \mu_0 - L\sigma\sqrt{\frac{\lambda}{2-\lambda}[1-(1-\lambda)^{2i}]} \tag{4}$$

where UCL is upper control limit, CL is control limit, LCL is lower control limit, i is sample at i order, λ is constant weight in range $0 < \lambda < 1$ and μ is mean of the process.

Control chart increase its sensitivity to detect abnormality process by dividing chart to three zones based on sigma values called zone rules as shown in Figure 42. Control chart will be evaluated to identify abnormality by using sensitivity rules [10][20]. Sensitivity rules provide criteria to find abnormality signal from data pattern as listed Table 1.

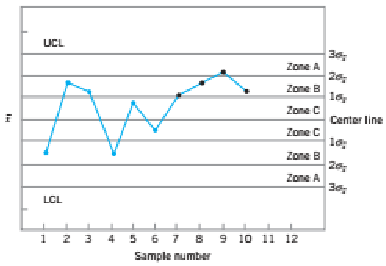


Figure 24. Zone rules.

Table 1. Sensitivity rules.

Standard Action Signal
1. One or more points outside of control limits.
2. Two of three consecutive points two-sigma warning limits.
3. Four of five consecutive points beyond one-sigma limits.
4. A run of eight consecutive points on one side of center line.
5. Six points in a row steadily increasing or decreasing.
6. Fifteen points in a row in zone C (both above and below the center line).
7. Fourteen points in a row alternating up and down.
8. Eight points in a row on both sides of the center line on both sides of the center line with none in zone C.
9. An unusual or nonrandom pattern in the data.
10. One or more points near a warning or control limit.

Cause and Effect Diagram

Cause and effect diagram is one of statistical process control to identify problem by classifying based on its group. Causes are put at the edge and effect is put at the end of the diagram. Causes consist of manpower, machine, material, method, measurement and environment factor. Cause and effect are used in this research to connect causes to the effect and find the relation. Cause and effect diagram is conducted by following steps [10][20]:

1. Identify problem to analyze;
2. Form team to analyze together;
3. Draw center and influenced factors;
4. Specify and classify the root cause based on category then correlate it to central line;
5. Analyze the root cause of each factor;
6. Sort the root cause start from the most influence factor;
7. List and execute countermeasure.

Five Whys Analysis

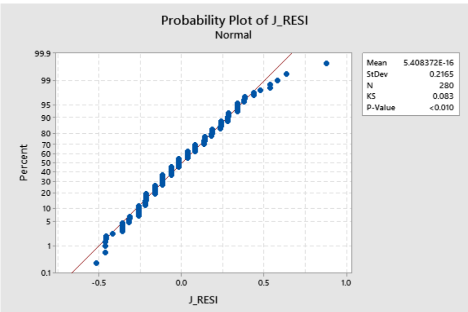
Repeated appeared problem is commonly only symptom of the more complex problem. Five whys is proposed technique to explore the knowledge from problem by asking questions five times ~~[10]~~[20]. The questions should be asked to right person who has appropriate background nor experience to acquire best answer. Five whys analysis illustrates the sequence of events that leads to main incident ~~[11]~~[21]. Five whys technique can be used independently or combine with another technique. This research combines five whys technique and cause and effect diagram. Defining problem aspect and category will be assessed by cause-and-effect diagram then exploring the root cause will be assessed by five whys analysis. Countermeasure is a complete action taken to solve the problem on the spot and take preventive measures so that similar problems do not happen again. It can be a form of process and tool improvements, making procedures to training users. Each root cause will be discussed by team to solve.

RESULTS AND DISCUSSION

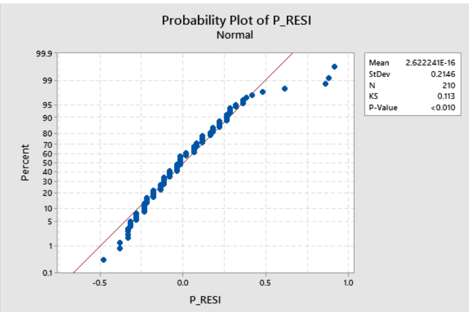
Process Stability

Process stability is assessed by reviewing control chart. Process is called as stable process if whole measurement point follow sensitivity rule. Each violation of the sensitivity rules cause process be unstable. Analysis should be conducted to identify the root cause. If violation point caused by assignable cause so it will be ignored. Violation point caused by special cause needs to analyze the root cause.

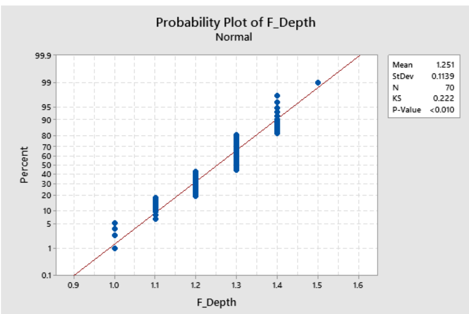
Commonly, most control chart is constructed based on normal distribution data assumption. The normal distribution shows the distribution of errors that are owned by the data. The normal distribution also shows how much the sample's ability to represent the actual data. Normal distribution status determines the technique used to process the data further. Data that is not normally distributed will use a different control chart with data that is normally distributed. The control chart that is built based on the assumption of a normal distribution cannot properly process data that is not normally distributed so there can be errors in describing the state of the process. Normal distribution data can be known th~~o~~rough normality test. Kolmogorov-Smirnov method is used in this normality test as shown in Figure ~~3~~5. Hypothesis used is H0 for data normally distributed (p-value > 0.05) and H1 for data not normally distributed (p-value < 0.05). Journal, pin and flange data has p-values < 0.05 so the data is not normally distributed. It also shown at the plot that points spread do not follow center line.



(a) Journal



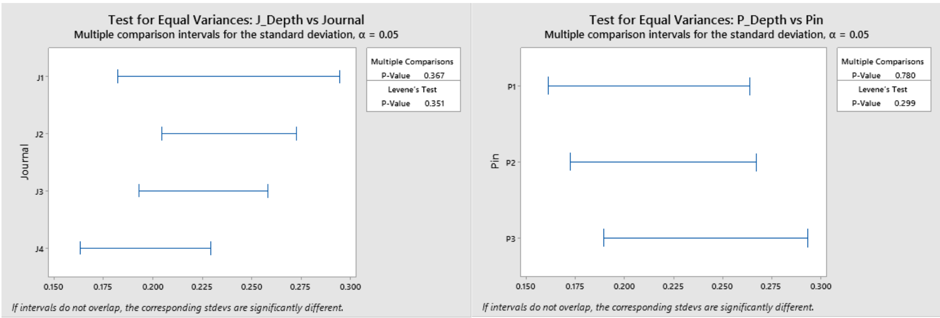
(b) Pin



(c) Flange

Figure 35. Normality test result.

Equal variance test is conducted to understand data similarity among whole journals data and pins data. Similarity shows data suitability to combine. The greater the similarity of the data or the smaller the variance that exists between the data, the greater the opportunity for the data to be combined and provide new knowledge. Selection of the right variance similarity test method requires information in the form of normality of data from each component. Levene test is used as shown in Figure 64 due to its ability to process non-normally distributed data. Hypothesis used is H0 for data has similar variance (p-value > 0.05) and H1 for data do not has similar variance (p-value < 0.05). Journals and pins data have p-values > 0.05 so the data have similar variance. It also shown at the plot that data component intersects each other.



(a) Journal (b) Pin

Figure 64. Equal variance test result.

The journal, pin and flange data owned are not normally distributed so they are not accurate when mapped on the Shewhart control chart. An alternative control chart that can accommodate the non-fulfillment of the assumption of normally distributed data is the EWMA control chart. In addition, the EWMA control chart is intended for data that performs data collection in the form of a single sample. The EWMA control chart is built through two parameters that must be determined, namely the sigma multiplier used at the control limit (L) and the weight value (λ) [10][20].

The control limit value used is 3 as defined by the standard rule and implemented by Minitab. In addition, the weight value used in making this EWMA control chart is 0.15. The weight value has an interval of $0.05 \leq \lambda \leq 0.25$. The smaller the value of , the better at detecting small shifts. However, it should also be noted that a small value of has an impact on decreasing the speed of the EWMA control chart in detecting shifts. The weighting of a small value has the consequence that the EWMA control chart has to go through more stages to move when detecting data from one side to the other.

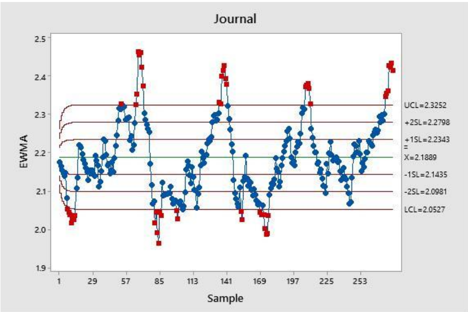
At λ=0.05 or λ=0.10, the EWMA control chart shows its best performance in detecting small data shifts including data that are normally distributed or data that are not normally distributed [10][20]. The selection λ of 0.15 is based on the best ability of the EWMA control chart in detecting data that is not normally distributed and considering the optimal speed in detecting shifts. In addition, based on trial and error conducted by the researcher, the use of λ=0.1 and λ=0.15 do not provide a significant difference. EWMA control chart shows journal, pin and flange process condition as shown in Figure 75. Journal, pin and flange EWMA control chart represent process condition is unstable which is shown by its violation against sensitivity rules.

Identification of the process is carried out after making the control chart. The identification process serves to assess the controllability of the process. The identification process seeks to find deviation patterns based on ten sensitivity rules. The process is said to deviate if there are points that are outside the control limit that indicate the variation of the process taking place. However, the product is declared to be a good product if it is still within the specification limit which indicates the criteria based on the specified standard.

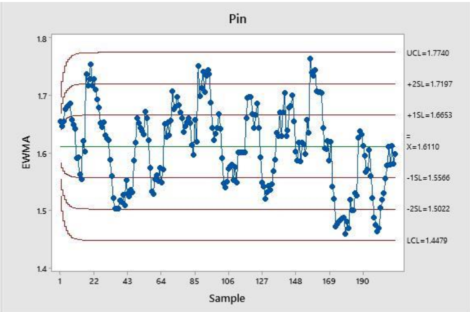
Journal EWMA control chart breaks sensitivity rules of one or more points outside of control limits, two of three consecutive points two-sigma warning limits four of five consecutive points beyond one-sigma limits, six points in a row steadily increasing or decreasing and one or more points near a warning or control limit. Journal EWMA control chart has the biggest violation among the parts. Pin EWMA control chart breaks sensitivity rules of two of three consecutive points two-sigma warning limits four of five consecutive points beyond one-sigma limits and six points in a row steadily increasing or decreasing. On the pin control chart there are no points that go out of the control limit. Flange EWMA control chart breaks sensitivity rules of one point outside of control limits, two of three consecutive points two-sigma warning limits and four of five consecutive points beyond one-sigma limits.

EWMA control chart results show whole crankshaft component process experience violation. A good process is a process that has high stability. Stability shows the variability that exists during the production process within a certain period of time. The smaller the level of variability, the more consistent and precise the production process will be. The process requires improvement to achieve stability through the elimination of deviant data. Each violation is analyzed to identify the cause classification which is conducted by comparing problem data point and problem report data at the day.

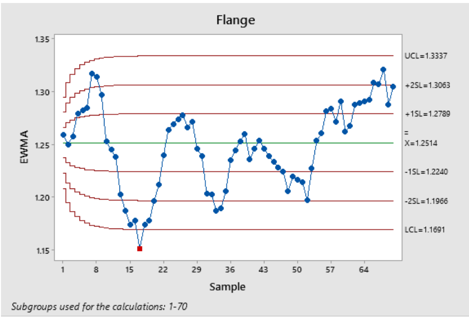
If there is no problem reported at the day in point concern, so the point will be classified as common cause. Violation which classifies as common cause will be ignored and violation which classify as special cause will be analyzed further.



(a) Journal



(b) Pin



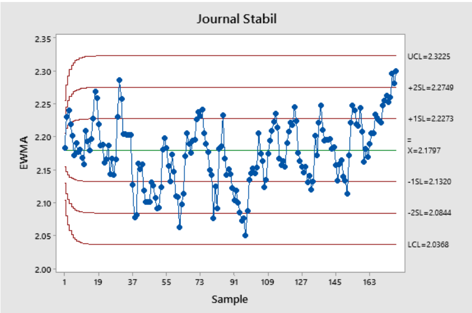
(c) Flange

Figure 7~~5~~. EWMA control chart design.

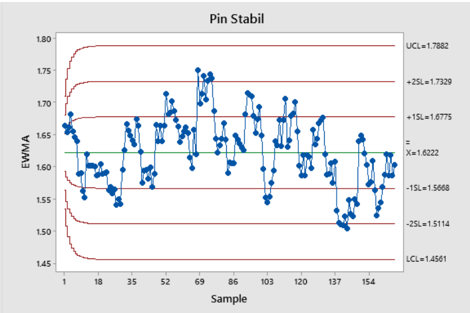
~~Journal EWMA control chart breaks sensitivity rules of one or more points outside of control limits, two of three consecutive points two-sigma warning limits four of five consecutive points beyond one-sigma limits, six points in a row steadily increasing or decreasing and one or more points near a warning or control limit. Journal EWMA control chart has the biggest violation among the parts. Pin EWMA control chart breaks sensitivity rules of two of three consecutive points two-sigma warning limits four of five consecutive points beyond one-sigma limits and six points in a row steadily increasing or decreasing. On the pin control chart there are no points that go out of the control limit. Flange EWMA control chart breaks sensitivity rules of one point outside of control limits, two of three consecutive points two-sigma warning limits and four of five consecutive points beyond one-sigma limits.~~

~~EWMA control chart results show whole crankshaft component process experience violation. A good process is a process that has high stability. Stability shows the variability that exists during the production process within a certain period of time. The smaller the level of variability, the more consistent and precise the production process will be. The process requires improvement to achieve stability through the elimination of deviant data. Each violation is analyzed to identify the cause classification which is conducted by comparing problem data point and problem report data at the day. If there is no problem reported at the day in point concern, so the point will be classified as common cause. Violation which classifies as common cause will be ignored and violation which classify as special cause will be analyzed further.~~

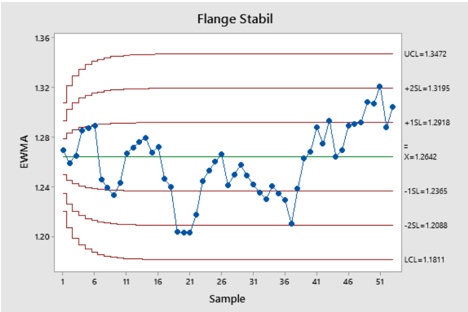
Special cause concerns should be overcome by finding the root cause. Assignable causes are disturbances in the process that cannot be controlled due to unusual activities or not natural variability, such as defective raw materials, machine setting errors and operator negligence. Assignable cause data can be identified and can be eliminated through improvements so that this data will be eliminated after countermeasure is applied to determine the stability of the process naturally. Control chart deviations are corrected by eliminating deviant points based on the sensitivity rule. Root cause and countermeasure of the concern will be explained in root cause analysis and process improvement parts. Control chart after countermeasure is shown in Figure 8~~6~~. Whole data follow sensitivity rules and within control limit and specification limit. In other word, control chart can be stated as stable process.



(a) Journal



(b) Pin



(c) Flange

Figure 86. EWMA control chart design.

Process Capability

Process capability is measured after the process is stated as stable process. Process capability measurement propose to figure out process ability to produce the product within desired specification. Process capability will determine at what vel the process is and what actions need to be taken to maintain, keep and improve quality. In addition, the frequency of checking carried out is also determined based on the capability value of a process. Process capability is symbolized by Pp and Ppk. Pp represent process potential could be reach if the process at minimally medium performance. Ppk evaluates the process capability through process assessment if it is not in the middle of performance and compares the shift to the middle performance process based on the specification limit. Ppk is also called actual process in the line due to its ability to represent better process capability. Pp and Ppk value is minimally 1.00 to state the process on good capability level and expected more than 1.00. The process capability can be calculated as follows [20],

$$\mathrm{Pp} = \frac{\mathrm{USL} - \mathrm{LSL}}{6\sigma} \tag{5}$$

$$\mathrm{P}pk = \min(\mathrm{P}_{pu}, \mathrm{P}_{pl}) \tag{6}$$

where USL is upper specification limit, LSL is lower specification limit, Cpu is Cp upper and Cpl is Cp lower.

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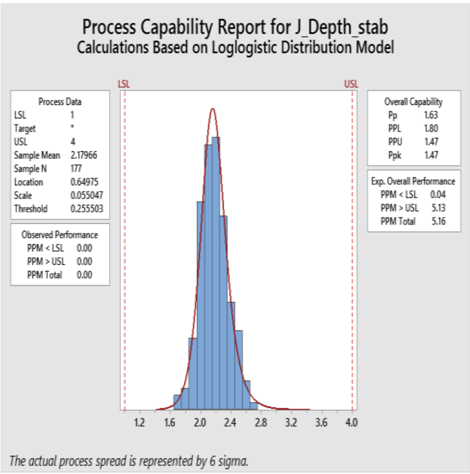
Pp and Ppk measurement is used to encompass whole process performance. Due to the data do not meet normality assumption, goodness of fit test is performed to obtain proper model for each capability measurement. Distributions are represented by LRT P-value follow determined hypothesis. Hypothesis used is H0 for data follow model distribution (p-value > 0.05) and H1 for data do not follow model distribution (p-value < 0.05) as shown Table 2.

Table 2. Goodness of fit test result.

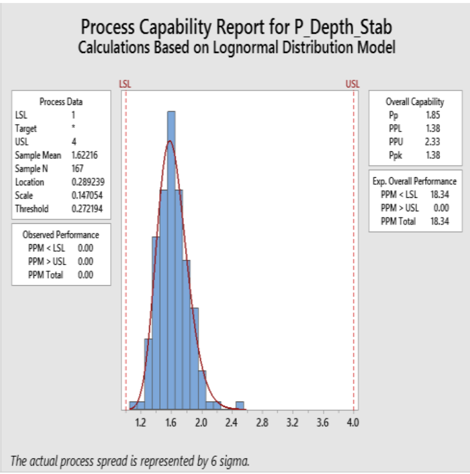
Component	Distribution	LRT P
Journal	3-Parameter Loglogistic	0.892

Pin	3-Parameter Lognormal	0.650
Flange	3-Parameter Weibull	0.990

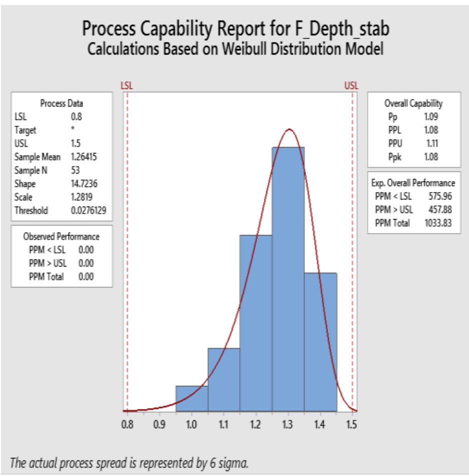
Data will be measured based on distribution model suitability. Goodness of fit test results show different distribution for each component. Then capability process is measured as shown Figure 79. Based on Pp Ppk value of journal, pin and flange process capability result, there are on good level of capability based on pp Ppk value > 1.00. All products are within specification limits and can be improved to improve performance. In addition, a reduction in the sample rate can be considered. The best capability result is showed by journal process. The Pp pin value which is greater than the Pp journal indicates the potential for pin processing that can be improved. In addition, the pin control chart before repair in the figure shows a more stable pin process than the journaling process.The flange process needs more attention due to its process capability result near to 1.00, so the natural tolerance is the same as the specification limit. If there is a slight deviation, it can reduce performance and result in points outside the control limit. The Pp and Ppk values of the flange are the lowest among journals and pins, so immediate repairs are needed.



(a) Journal



(b) Pin



(c) Flange

Figure 97. Process capability result.

Root Cause Analysis

Control charts have a major role to improve processes. It is known that, firstly in general, running processes are dominated by processes that are not running under statistically controlled conditions. Second, the root cause of the problem comes from a special cause which if it can be eliminated from the process, the variability can be reduced and the process can perform better. This identification can be conducted easier by using a control chart. Lastly, an active role from the management level to the operator in the form of corrective actions is very important in an effort to eliminate special causes because the control chart can only identify problems.

Each problem needs proper countermeasure to eliminate the concern. Countermeasure works well when it reach the root cause of the problem. It it essential to analyze each concern till find the root cause. Each concern is analyzed by classifying into six groups which is represented by cause-and-effect diagram as shown in Figure 810.

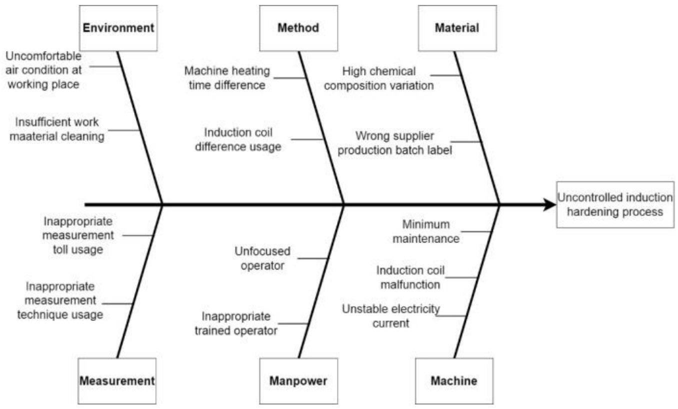


Figure 108. Cause and effect diagram of crankshaft hardness concern

Cause and effect diagram classifies concern based on factors which consist of material, method, manpower, machine, measurement and environment. Each factor is explored deeper by using five whys analysis to reach the root cause as shown in Table 3. Concern from factors are analysed into last why to obtain root cause source. A phenomenon from a factor may come from another factor, so it also may affect another factor. A phenomenon from environment factor is caused by machine factor which is insufficient filter specification. Phenomenon from measurement factor is affected by manpower factor which is related to manpower skill and knowledge. Phenomenon form method factor comes from material factor due to its composition and dimension. There needs to be an in-depth and integrated analysis between factors to be able to find the root of the problem and the right solution.

Table 3. Five whys analysis.

Factor	Phenomenon	Last Why
Environment	Uncomfortable air condition at working place	Insufficient filter specification
	Insufficient work material cleaning	Open coolant container
		Dirty environment
Measurement	Inappropriate measurement tool usage	Incomplete training of measurement tool usage
	Inappropriate measurement technique usage	Minimum product knowledge
Method	Machine heating time difference	Material composition change
	Induction coil difference usage	Component dimension difference
Manpower	Inappropriate trained operator	Existing operator change
	Unfocused operator	Repeated activity for long time
		Unfit condition
Machine	Induction coil malfunction	Reach coil usage life
		Manufacturing defect
	Unstable electricity current	Pest attack to cable
	Minimum maintenance	New machine lack of knowledge

Material	High chemical composition variation	Raw material variation
	Wrong supplier production batch label	Supplier misunderstanding

The environment factor contributes two phenomena that cause instability. An uncomfortable working environment affects the operator's performance which decreases because it is not focused so that there can be negligence on crankshaft processing. An environment that has a lot of smoke comes from a machine with insufficient air filter capability. Poor material cleaning is related to the crankshaft washing process environment. The crankshaft which still has impurities in the journal, pin and flange components have the potential for imperfections in the induction hardening process. Therefore, these two phenomena are also related to the condition of other machines, namely washing machines and turning machines. The measurement factor contributes two phenomena that cause instability. Inappropriate measuring tools and measurement techniques affect the measurement results. Inappropriate measuring tools usage are caused by operator error in using the jig holder sensor and inappropriate measurement techniques usage are caused by the absence of rules in the measuring position. Therefore, these two phenomena are also related to the manpower and method factors.

The method factor contributes two phenomena that cause instability. Machine heating time difference and induction coil difference usage. The difference in heating time affects the hardness case depth results. The initial heating time has a standard from the machine maker and the company but is still returned to each factory to adjust the heating time in order to achieve the expected hardness case depth. The difference in the use of induction coils affects the variation in results because it uses three different induction coils, namely induction coils for journals, pins and flange. Therefore, these two phenomena are also related to machine and material factors. The manpower factor contributes two phenomena that cause instability. Operators who are poorly trained usually occur when there are new operators who are still adapting and have not been able to work optimally. This has an impact on work such as improperly positioning the crankshaft on the engine. Unfocused operator is a common occurrence caused by individual operator factors such as health conditions. The effect of unfocused operator also due to as the effect of a new operator.

The machine factor contributes three phenomena that cause instability. The induction coil malfunction causes the hardness case depth results to vary after the induction hardening process or do not meet the standards. Induction coil malfunctions are caused by the age of the coil that has reached its age or defects in the coil. Unstable electric current causes the induction process to be disrupted so that the engine cannot reach its optimal performance. This is caused by the wires being chipped by pests. Lack of maintenance causes the machine not to work in its optimal performance. The lack of knowledge of the maintenance team because it is a new machine is a contributing factor. Therefore, these two phenomena are also related to man power and environmental factors.

The material factor contributes two phenomena that cause instability. High variations of chemical composition causes high variations results of high hardness case depth as well. This is caused by raw material suppliers who cannot control raw material composition properly. There needs to be a notification to the supplier of raw materials to improve the process. Incompatibility of supplier production batches can cause variation in results because each batch of raw crankshaft production has a different level of material concentration, so it is necessary to set the machine if the measurement results due to variations in material concentration differ much from the target. This is due to raw crankshaft suppliers who mix production batches of regular products with hold products which they usually separate for investigation.

Process Improvement

Concern will never appear again if countermeasure is implemented to the root cause. Moreover, improvement actions prevent similar concern occur. Countermeasure is conducted based on standard and experience of the team as shown in Table 4. Advice from other plant counter partners and machine makers are considered to obtain appropriate solution.

Table 4. Process improvement analysis.

Factor	Root Cause	Countermeasure	Improvement
Environment	Insufficient filter specification	Filter change	Upgrade filter specification
	Open coolant container	Coolant change	Coolant container coverage
	Dirty environment	Environment cleaning	Working place cleaning standard
Measurement	Complete training of measurement tool usage	Usage training	Routine usage training and evaluation
	Minimum product knowledge	Knowledge product training	Routine knowledge training and evaluation
Method	Material composition change	Machine setting	Routine material composition information document
Manpower	Existing operator change	Operator training	Skill evaluation control
	Repeated activity for long time	Working area change	Break time resetting
	Unfit condition	Operator change	Routine supplement consumption
Machine	Reach coil usage life	Coil change	Upgrade coil specification
	Manufacturing defect	Coil change	Supplier change

	Pest attack to cable	Cable change	Pest trap
	New machine lack of knowledge	Routine maintenance	Machine study comparison
Material	Raw material variation	Machine setting	Improve raw material variation stability
	Supplier misunderstanding	Raw crankshaft separation	Supplier understanding and standard sharing

Countermeasure and improvement are implemented to each factor and related factor inside the concern. Environment concerns focus on environment itself and machine issues. Measurement concerns handle measurement and also manpower issues. Method concerns overcome not only method but also material issues.

CONCLUSION

In this research, process stability and capability of crankshaft hardness process are delivered. The induction hardening process is experiencing instability which is indicated by process deviations based on the journal, pin and flange control chart. Deviations on the control chart are indicated by points that are outside the control limit, two of three consecutive points outside the two sigma line, four of five consecutive points outside the one sigma line, six points consistently increasing or decreasing or there are points that are near control limit. Hardness case depth quality is affected by six factors that contribute instability individually or influence each other. Furthermore, concern which affect its stability is analyzed to find the root cause. Solution is implemented based on root cause to guarantee its effectiveness to eliminate the issue. Improvement is conducted to prevent similar concern appear in the future.

EWMA control chart shows its capability to process non normal distribution data very well. EWMA control chart is capable to show data violation of the process. The sensitivity rules help the control chart in identifying process abnormalities that appear clearly and potential abnormalities. Cause and effect diagram classify concerns based on factor cause to help identify the issues easier. Five whys technique does work to find and analyze the root cause based on cause and effect diagram classification problem. Cause and effect diagram and five whys technique are good combination to find the concern and identify real root cause.

Cause and effect diagram and five whys analysis find the root cause of the problem which can then be countermeasured directly including replacing the operator immediately if the operator experiences a problem, changing the coil if the depth of hardness result is not reached minimun standard or approaching the lower limit and checking the cable condition if the machine process is unstable. In addition, prevention actions can be taken against six factors of elements including operator training and operator change for labor factor, coil changes, cable changes and maintenance and repairs for machine factor, machine settings and crankshaft separation according to production batches for material factor, routine filter changes and routine cleaning of the work area for environmental factor, usage training and product knowledge training for measurement factor and machine settings for method factor.

Crankshaft hardness process is unstable which shown by its violation of sensitivity rules on control chart. The capability of the induction hardening process is good enough, which is indicated by the Pp Ppk value. The journal process is worth Pp 1.63 and Ppk 1.47, the pin process is Pp 1.85 and Ppk 1.38 and the flange process is Pp 1.09 and Ppk 1.08. All products within the specification limit. In addition, a reduction in the sample rate can be considered. However, the Pp and Ppk flange numbers which are still worth one indicate that the natural tolerance is the same as the specification limit, so that if there is a slight deviation it can reduce performance and result in points outside the control limit so that it needs to be improved. Implemented countermeasures work effectively to improve process stability.

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Commented [R8]: More references were added

Response to Reviewers Comments

Paper Title: Crankshaft Hardness Quality Evaluation of Passenger Car

Paper Number:

No.	Reviewer's Comment	Author's Response (Clearly indicate page and paragraph of changes)
1	Elaborate conclusion with sufficient outcomes	Managerial implications for sufficient outcomes are added (page 13 in the 3rd paragraph)
2	References are not sufficient (add some relevant references)	More references are added (page 13 in the references [9] – [19])
3	Should explain motivation in conducting this research	The motivation for conducting this research is explained and supported by some references (page 2 in the 6th paragraph)
4	Problem statement is not clearly defined.	Problem statement is explained based on occured problem and references (page 2 in the 7th paragraph)
5	Lack of literature related with quality	More literature related with quality are added (page 3 in the 1st and 4th paragraph of measurement process sub-theme)
6	Detail methodology should be presented	Detail methodology is presented by added flow process (page 3)
7	No explanation on the studied process	Studied process is explained in material sub-theme (page 2)
8	No explanation of the scope of process covered in this research	Scope of process covered is explained in material sub-theme (page 2)
9	No explanation on data collection methodology	Data collection is explained in data collection and process sub-theme (page 2)
10	No explanation on data confirmation	Data confirmation is explained in data collection and process sub-theme (page 2)
11	All related assumptions	Related assumptions are explained in material sub-theme (page 2)
12	Enhance the reference by citing related & recent papers (last five years)	More references are added (page 13 in the references [9] – [19])

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