DECISION SUPPORT SYSTEM FOR DETERMINING POWER LOSS AND REFURBISHABILITY OF FAILED AUTOMOTIVE PETROL ENGINE BLOCK AND CRANKSHAFT

Basil O. Akinnuli 1, Oladele O. Awopetu 2, Oluwaseun O. Ojo 3

1,2 Department of Industrial and Production Engineering, Federal University of Technology Akure, P.M.B. 704, Akure, Nigeria
3 Department of Mechanical Engineering, Adeleke University, P.M.B. 250, Ede, Nigeria

Corresponding author: ojo.oluwaseun@adelekeuniversity.edu.ng

ABSTRACT: The crankshaft and engine block of automobile wear or fail after certain years of usage. The cause of failure is a contributing factor to the power loss of the engine. Power loss reduces the performance of the vehicle. Due to the economic situation in Nigeria, the cost of buying new engines is usually high and some used engines have problems that are latent. Pre-test engine analysis was carried out and torque of each selected engine was measured with a dynamometer to know the speed of the worn engine. Disassembly of four (4) cylinder engines namely; Toyota, Nissan, Mitsubishi, and Mazda were carried out and the affected failed parts, namely; main bearing, crankpin journal, and bore cylinder diameter were determined and the level of their wear as well as power losses ascertained using measuring instruments. For easy computation and analysis, a computer software using C-sharp programming language was developed to determine the power loss and predicting machining level of refurbish-ability and tested for performance evaluation. The model and its developed software are decision support tools for any automotive industry where maintenance and management of engines for improved performance and efficiency of operation is the focus.

Keywords: Wear; Performance of the Vehicle; Power loss; Economy; Torque; Cylinder engines; Computer software; C-sharp.

NOMENCLATURE

\( R_f \) Refurbish-ability of sample inspected (mm)
Note: Y can be \( Y_1 \), \( Y_2 \) also X can be \( X_1 \) or \( X_2 \)
\( Y_1 \) Standard manufacturing value for main bearing journal (mm)
\( Y_2 \) Standard manufacturing specification for crank pin journal (mm)
\( X_1 \) Value inspected and measured for main bearing journal (mm)
\( X_2 \) Value inspected and measured for crank pin journal (mm)
\( A_s \) is the area of the standard bore diameter (\( mm^2 \))
\( n_c \) is number of cylinders considered in the engine block,
\( L \) is stroke of the piston (mm)
\( S_e \) is engine size capacity of the standard engine based on manufacturing specification.
\( A_w \) is area of the worn engine diameter (\( mm^2 \)),
\( S_w \) is engine size capacity of the worn engine (\( mm^3 \)),
\( D_w \) is the bore diameter of the worn engine (mm),
\( P_{mw} \) is mean effective pressure of the worn engine (Nm/mm^2),
\( T_w \) is torque of the engine that was measured with the aid of dynamometer,
\( N \) is number of revolution per power stroke for 4 - stroke engine (\( n = 2 \)).
\( A_w \) is area of the worn engine diameter (\( mm^2 \)),
\( L \) is stroke of the piston (mm),
\( D_w \) is the bore diameter of the worn engine (mm),
\( P_{mw} \) is the mean average effective pressure of the standard engine constant = 0.7 - 0.9 N/mm^2,
\( N_e \) is Average speed of the engine by specification at full speed in Rev/min
\( S_e \) is engine size capacity of the standard engine based on manufacturing specification.
N is number of revolution per power stroke for 4-stroke engine \((n = 2)\).

\[ P_{\text{wm}} \] is the mean effective pressure of the worn engine \((N/mm^2)\).

\[ N_w \] is average speed of the worn engine in r.p.m.

\( S_w \) is engine size capacity of the worn engine \((mm^3)\).

\( N_w \) is number of revolution per power stroke for 4-stroke engine \((n = 2)\).

\( P_S \) is the standard engine power (watts)

\( P_w \) is the worn engine power

\( P_L \) is the loss in engine power (watt) when the cylinder block has reduced its efficiency

\( P_{\text{sr}} \) is Engine power after refurbishment

\( P_{\text{fr}} \) is Engine power before refurbishment

\( n_c \) is number of cylinder considered and \( L \) stroke length (mm)

\( L \) is stroke of the piston (mm),

\( S_w \) is engine size capacity of the worn engine \((mm^3)\).

\( S_S \) is engine size capacity of the standard engine based on manufacturing specification.

1. **INTRODUCTION**

According to Baffour-Awuah (2018), automotive maintenance is much talked about globally, yet it is generally accepted that, people have no maintenance culture. Little is given to automotive maintenance planning. Poor maintenance arises from the lack of proper management than from the lack of technical expertise (Velimirović et al., 2016). Sun et al., (2019), and Chanda (2001), reported that automotive maintenance is the act of inspecting or testing the condition of car subsystems (e.g. engine) and servicing of worn replacing of parts and fluids. Regular maintenance is critical to ensure the safety, reliability, drivability, comfort and longevity of a car. During preventive maintenance, a number of parts are replaced to avoid major damage for safety reasons. Ochi (2002), Ganchy and Chanda (2003), added that unnecessary breakdown often occur in industrial sub-system because management fails to put facilities in place within the organization to maintain the reliability of the system at reasonable level. Engine block is the main housing of hundreds of parts found in modern engines. It is found to be the largest part that constitutes 25% to 30% of the total weight of the engine (Izogo and Ogba, 2015; Ochi, 2002). The crankshaft, as stated by Ganchy and Gancher (2009) and Nadolny (2012), has three main components; the crank pin journal or big end which is the running surface of the crankshaft which receives the energy produced by the controlled explosion within the engine. The main journal carries the crankshaft within the main bearings and crank webs which connect the two together and the long crankshaft suffers from unacceptable amount of flex, higher compression ratios and high rotational speeds (Martins, 2005; Nunney and Malcom, 2007). Mohd and Jadoun (2015), Takemasu and Nadolny (2012), also mentioned that every piston fires at a different instant in time, which creates vibrations in the crankshaft that grow in magnitude with the number of cylinders, the length of crankshaft and engine speed. The constant pounding and stress may cause small airtime cracks to develop in and around journals, and particularly around oil hole. Reducing the power losses and wear of the automotive engine that are subjected to relative motion is very important in the operating efficiency of automobile vehicle. Engine speed is the major operating parameter, torque or efficiency that control the power losses (Taiwo and Oladeji, 2003; Mavrigian, 2009). The distribution of component failures and causes as analyzed by Jonathan (2002), are shown in the pie chart in Figures 1. In the chart, it was revealed that Engine Crankshaft and Block take 55% of engine failure.

![Figure 1. Distribution of Components Failures](Image)

Source: (Jonathan, 2002)

In most reconditioning workshop in Nigeria, major decisions were made based on brain storming and no scientific
approach. This led to engines failure without proper management and lack of finance or fund. Based on the shortcomings, a software was developed to predict machining process of refurbish-ability and determine power loss and its cost implication. This would give the engineers an insight of the completion time and cost implication. This study provides access to a wide variety of specifications for automotive engine crankshaft and block; and creates an interface for maximum allowable range of failures, determines power loss and makes easy computation and analysis, increases time of predicting machining operations and reduces drudgery which leads to human error.

2. METHODOLOGY
The method used to achieve the objectives of this research include: Pre-Test engine which involved high consumption of engine oil and thick dark blue smoke from the exhaust, foreign noise from the engine, low oil pressure, low compression, water mixing with oil in the engine, determination of the torque before disassembly, disassembly of the engine to determine the affected unit of crankshaft or engine block, analysis of the affected unit by reason of metrology, ascertaining the required models for determining the power loss and refurbish-ability of the affected engine, development of logic (flowchart) and algorithm required, development of the software and finally apply the developed model and its software for performance evaluation on the case studies for decision making.

2.1 Field Survey of Crankshafts and Engine Blocks Failure
Several automobile and machine tools service workshops were visited to under study causes of failure, methods for repair, procedural analysis of failed crankshaft and engine block as well as data collection. The failed components as well as types of vehicles affected were shown in Tables 1.

| S/N | Workshop                        | Failed Engine Parts                  | Type of Vehicle          |
|-----|---------------------------------|--------------------------------------|--------------------------|
| 1.  | APEX engineering works, Ilorin, Kwara State. | Failed engine block and crankshaft   | Toyota corolla           |
| 2.  | Oyeladun engineering works, Owode, Oyo State. | Failed engine block                  | Mazda 626 and Toyota corolla |
| 3.  | State Technical Services, Ogbomosho, Oyo State. | Failed engine block and crankshaft   | Nissan L1600              |
| 4.  | New breed automobile engineering services, Sango Ibadan, Oyo State. | Failed engine block and crankshaft   | Mazda 626, Toyota corolla, Nissan L1600 and Mitsubishi lancer. |

2.2 Model Development
(a) Computation for wear in engine crankshaft
The computation for the wear value was carried out using the equation 1 by Fonte (2008), and the result gotten are shown in Table 2
\[ R_f = Y - X \]  

(b) Estimation of the power loss was calculated from the equation shown below
Engine Capacity: This is the engine capacity based on the vehicle brand specification before wear occurs. The engine capacity for the block was estimated from equation 2 by Mangartz (2010), and Mavrigian (2009).
\[ S_s = A_s \cdot n_c \cdot L \]  

The engine capacity for the worn engine was calculated from equation 3
\[ S_w = A_w \cdot n_c \cdot L \]  

(c) Reduction in Engine Capacity
The engine capacity after worn was given from equation 4
\[ S_{wl} = S_w - S_s \]  

(d) Determination of the Refurbish-ability of the Worn Engine Block
This was estimated using Equation 5 and Figure 2 as illustrated.
\[ R_{fb} = D_w - D_s \]
Determination of mean effective pressure (M.E.P)

The mean effective pressure of the worn engine was given in equation 6 by Changli and Wang (2005).

\[ P_{m_w} = \frac{A_w}{L} \times 2 \times \pi \times n \]

\[ A_w = \frac{\pi}{4} D_w^2 \]

Determination of engine power output of the standard engine is the power required in the standard engine and was calculated from equation 7 by Paswan, and Hayes (2008).

\[ P_s = \frac{P_{m_s} S_s N_s}{60000} \]

Determination of power of worn engine

This is the power lost when the cylinder engine has reduced its efficiency after worn and calculated from equation 8 by Dunford (2011).

\[ P_w = \frac{P_{m_w} S_w N_w}{60000} \]

Determination of the engine power

This was estimated from equation 9 by Dunford (2011):

\[ P_l = P_s - P_w \]

Percentage power loss to specification

The percentage power loss due to wear was calculated from equation 10.

\[ \%P_l = \frac{P_l}{P_s} \times 100 \]

2.3 Scenarios for Decision Making

There are four scenario for decision making as concerns boring to accommodate categories of cylinders over-size (next standard sizes) and they are:

a. 010 piston: These cylinder sleeves have sizes that are 0.010 inch (0.25mm) larger than the standard piston sizes for the affected engine. It means the cylinder needs to be bored to accommodate the size of this piston (0.010 inch larger than the standard bore size) (Patton et al., 1989).

b. 020 piston: This cylinders have sizes that are 0.020 inch (0.50mm) larger than the standard piston sizes for the engine. It means the cylinder needs to be bored to accommodate the size of this piston 0.020 inch (0.50mm) larger than the standard bore size (Chandra and Chanda, 2009).

c. 030 pistons: These cylinders have sizes that are 0.030 inch (0.75mm) larger than the standard piston sizes for the engines concern. It means the cylinders will be bored to accommodate the size of this piston 0.030 inch (0.75mm) larger than the standard bore size) (Dodge, 2002).

d. 040 pistons: These cylinders have sizes that are 0.040 inch (1.00 mm) larger than the standard piston sizes for the engine concern. It means the cylinders will be bored to accommodate the size of this piston (0.040 inch larger than the standard bore size) (Spiteri, 2005).
2.4 Model Applications

Table 2. Crankshaft parameters and their values for computation using Equation 1

| Type of Engine and Model | Standard specification for main journal diameter ($y_1$) (mm) | Standard specification for crankpin diameter ($y_2$) (mm) | Main Journal measurement $x_1$(mm) | Crankpin measurement $x_2$(mm) | $R_f$ of main bearing journal $y_1 - x_1$ (mm) | $R_f$ of crankpin $y_2 - x_2$ (mm) |
|--------------------------|-------------------------------------------------------------|-----------------------------------------------------------|-----------------------------------|---------------------------------|---------------------------------------------|--------------------------------|
| Toyota Corolla           | 50.00                                                       | 42.00                                                     | 49.85                             | 41.80                           | 0.15                                        | 0.20                                        |
| Nissan L1600             | 54.96                                                       | 49.96                                                     | 54.80                             | 49.81                           | 0.16                                        | 0.15                                        |
| Mitsubishi Lancer        | 47.96                                                       | 44.98                                                     | 47.79                             | 44.87                           | 0.17                                        | 0.11                                        |
| Mazda                    | 59.90                                                       | 50.95                                                     | 59.79                             | 50.79                           | 0.20                                        | 0.16                                        |

2.5 Determination of wear in the engine block case study

The level of wear was determined with the use of inside micrometer gauge. The level of wear for proper refurbishing method of each engine block selected was obtained by comparing the standard bore diameter with the measured value to ascertain the level of wear and refurbish-ability of the block as shown in Table 3.

Table 3. Engine block parameters and their values for computation using Equation 5

| Type of Engine and Model | Standard specification for bore diameter ($D_w$) (mm) | Measured bore diameter ($D_w$) (mm) | $R_f$ of the engine block $D_w - D_z$ (mm) | Stroke of the engine block (mm) | Torque measured with dynamometer ($T_w$) (Nm) |
|--------------------------|-------------------------------------------------------|-----------------------------------|------------------------------------------|---------------------------------|---------------------------------------------|
| Toyota corolla           | 75.00                                                  | 75.35                             | 0.35                                     | 66.00                           | 68.00                                       |
| Nissan L1600             | 85.00                                                  | 85.60                             | 0.60                                     | 78.00                           | 70.00                                       |
| Mitsubishi Lancer        | 76.00                                                  | 76.85                             | 0.85                                     | 75.00                           | 75.00                                       |
| Mazda                    | 85.00                                                  | 85.15                             | 0.15                                     | 70.00                           | 65.00                                       |
STEP 1
Select Type of Vehicle & Model

STEP 2
Select Activities
- Crankshaft
- Engine Block

STEP 3
Compute for Engine Block Failure

STEP 4
Input Parameters:
\( D_w, D_s, A_w, L, S_w, S_p, n_c, n_s, N_w, P_m, P_m, P_m_u \)

STEP 5a
Input Parameters:
\( Y_1, X_1, Y_2, X_2 \)

STEP 5b
Compute Initial Power Loss:
\[
\begin{align*}
& a) P_{m_w} = \frac{T_w \cdot N_w \cdot 2\pi}{A_w \cdot L} \\
& b) P_s = \frac{P_{m_s} \cdot S_p \cdot n_s}{60000} \\
& c) P_w = \frac{P_{m_w} \cdot S_w \cdot N_w \cdot n}{60000} \\
& d) P_l = P_s - P_w \\
& e) S_s = L \cdot n \cdot \frac{X}{2} \cdot D_s^2 \ldots 3.3 \\
& f) S_w = L \cdot n \cdot \frac{X}{2} \cdot D_w^2 \ldots 3.4 \\
& g) W_l = S_w - S_s \ldots 3.5 \\
& h) R_{f_b} = D_w - D_s \ldots 3.6
\end{align*}
\]

STEP 6a
Select Type of Vehicle & Model

STEP 6b
Select Activities
- Crankshaft
- Engine Block

STEP 6c
If “a” Machine To 0.25
“b” Machine To 0.50
“c” Machine To 0.75
“d” Machine To 1.00

STEP 6d
Select the Greater Value for Both & Machine

STEP 7
Compute: \( R_c f \)
Main bearing wear limit = \( Y_1 - X_1 \ldots 3.2a \)
Crankpin Wear Limit = \( Y_2 - X_2 \ldots 3.2b \)

STEP 8
If “a” Machine To 0.25
“b” Machine To 0.50
“c” Machine To 0.75
“d” Machine To 1.00

STEP 9
If “a” Machine To 0.25
“b” Machine To 0.50
“c” Machine To 0.75
“d” Machine To 1.00

STEP 10
Compute Final \( P^1_{loss} < P_{loss} \)

Figure 3. Logic Flowchart for the Software
2.6 Software Development Logic

Logic for the software development is shown in Figure 3 above. This was developed putting into consideration the mathematical models developed and integration of the models for decision making.

2.6.1 Software Interface Design

The software has two major interfaces:

First Interface

Figure 4 represents the start-up page while Figure 5 represents the loading page which introduces the software. Figures 6 and 7 displayed new information and add the name of the automobile respectively.

Figure 4. Start Interface

Figure 5. Splash screen prepares the loading of the software

Figure 6. Main Database Update
The Menu Interface
This represents the menu option page and it also begins with the user side of the package. On this interface, we have the scroll of the crankshaft standard specifications, bore diameter, measured values, stroke of the piston as shown in Figure 8.

Material Selection Interface
This is the major interface of the software. It consists of twenty five common vehicular crankshaft, engine block type and model, etc. This interface has different sections in it such as: Crankshaft Specification, Stroke of the Piston, Bore Diameter and Measured Values as displayed in Figure 9.
3. RESULTS AND DISCUSSION

This interface displays the suggested power loss, refurbish-ability requirement with their respective index value. It can also be printed. Figure 10 displayed the vehicle parameters and its measured values while Figure 11 showed the results. Figure 12 and 13 showed the power loss and boring diameter determination while Figure 14 displayed the performance test of the failed engine block and crankshaft of Nissan product. Table 4 showed the performance comparison before and after refurbishment.
Figure 14. Performance test using the failed engine block and crankshaft (Nissan)

Table 4. Performance Comparison Before and after Refurbishment

| S/N | Vehicle         | Initial performance (kW) | Final performance (kW) | Power Loss (kW) | Percentage Loss (%) | Percentage Improvement (%) |
|-----|----------------|--------------------------|------------------------|----------------|---------------------|--------------------------|
| 1   | Mazda 626(A)   | 3267.65                  | 5720.63                | 2.45297        | 42.88               | 0.58                     |
| 2   | Toyota Corolla (B) | 3988.27                  | 6298.92                | 2.31065        | 36.68               | 0.39                     |
| 3   | Nissan L16(C)  | 5864.95                  | 8499.23                | 2.63428        | 30.99               | 1.7                      |
| 4   | Mitsubishi Lancer(D) | 5655.30                  | 7350.01                | 1.69451        | 23.05               | 2.5                      |

From the analysis carried out, it was discovered that percentage improvement has met the manufacturer's new dimensional fits, limit and conform to new engine standard which gives satisfactory performance. The engine compression was checked in each of the engine cylinders by measuring slight variation in engine cranking speed. It was discovered that the engine has been restored and provided much more power and allow engine to be more efficient at proper revolution per minute (rev/min) with increase in power output. The power output, torque and speed are of premium importance in the operation of automobile engines. However, if percentage improvement is very low after refurbishing, the power output, speed responsiveness of the engine compression will be very low.

4. CONCLUSION
The above analysis and test showed that the system satisfies its intended reasons for development which are, its ability to determine the power loss and also predict accurately the machining values required for reconditioning both crankshaft and engine blocks for better performance. Therefore, this new displacement was the result of boring the cylinders and installing new pistons which are; Analysis A (0.25mm), Analysis B (0.50mm), Analysis C (0.75mm), Analysis D (1.00mm). Now each cylinder will meet the manufacturer's specifications because excessive cylinder taper and out of round conditions have been resolved. The engine would give many rules of satisfactory service regarding the pistons and block assembly. Since boring increases the diameter of the cylinder after it is bored, it will be greater than the diameter of the old piston. Hence, the piston of the same size with the bored cylinder were used.

5. DECLARATIONS
5.1 Availability of data and materials
Data collection was made available while visiting several workshops to know the causes of failure, methods for repair, and procedural analysis of failed crankshaft and engine block as shown in Table 1.

5.2 Competing interest
Authors declare no possible conflict of interest in this particular manuscript.

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5.4 Authors' contributions
This work was carried out in collaboration among all authors. Author 1 designed and analyzed the study, wrote the first draft of the manuscript. Author 2 and Author 3 managed the analysis of the study. Author 3 managed the literature searches. All authors read and approved the final manuscript.
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REFERENCES

Baffour-Awuah E: Service Quality in the Motor Vehicle Maintenance and Repair Industry. A Documentary Review: International Journal of Engineering and Modern Technology. 2018, 4:1.
Chanda P: Industrial and System Engineering. 2001. 2:6. p. 30-35. ISBN 1-7358-5078-3.
Chandra P, Chanda A: Quality Tools to Reduce Crankshaft Forging Defects: An Industrial Case Study. Journal of Industrial and System Engineering. 2009, 3:1.
Changli T, Wang P: Analysis of an Unusual Crankshaft Failure. Engineering Failure Analysis. 2005, Vol. 12, 0, p. 465-473. Dodge S: Automotive Diagnostic and Repair Developments. https://www.aai1car.com/tech. 2002. p.1-3.
Dunford C: Purpose, Design and Typical Problems of Crankshaft CSL Technical Forces. 2011. https://www.cslglobal.com. Accessed 15/10/2014.
Fonte M: Marine Main Engine Crankshaft Failure Analysis; A case study. Engineering Failure Analysis. 2008. Vol 16, pp. 1940-1947.
Ganchy S, Chanda P: Technical Developments and Recent Trends in Crankshaft Materials. 2003. p.51. ISBN 1-5983-6754-1.
Ganchy S, Gancher S: Automobile Petrol Engine Design for Frictional Losses. The Rosen Publishing Group. 2009, p. 41, ISBN 1-4358-5066-1.
Grewe K: Die Relief dastellingeinerantikenSteinsgemaschineEug. Hierapolis in Phrygein und ihreBedentung fur die Technilgeschienhte. Peterburg Press, Germany. International Konfenenz. 2009. 13-16.
Izogo EE, Ogba I: Service quality, customer satisfaction and loyalty in automobile repair services sector. International Journal of Quality & Reliability Management. 2015. 32:3.
Jonathan W: Fatigue Performance Comparison and prediction of cast iron Crankshaft refurbishing. Engineering failure analysis. 2002, Vol 6, p. 133-167.
Mangartz F: Internal Combustion engine and Automobile vehicle. Allysian Press, Canada. 2010, Vol.42. p.1-9. ISBN 987-3-88467-149-8.
Martins P: Crankshafts, stock and performance. Michigan Press, UK. 2005, Vol. 1, p.30. ISBN 978-3-78523-149-7.
Mavrigian M: Forged Crankshaft Technique. Precision Engine, the Engine Specialists Technical and Performance Resources. 2009, p. 1-6. www.precisionengintech.com/tech. accessed 18/7/2014.
Meh T, Jadoun T, Evaluation of Service Quality in Two Wheeler Automobile Industries Using Servqua Model. International Journal of Innovative Research in Science, Engineering and Technology, 2015, 4:5.
Nadolny K: The Method of Assessment of the Grinding Wheel Cutting ability in the plunge Grinding. Central European Journal of Engineering. 2012, 2:3.
Nunney, Malcolm J: Light and heavy vehicle technology. Elsevierbutterworth-heinemann. 2007, 4th edition, ISBN 978-0-7506-8037-0.
Ochi: Automobile principles of cylinder block. 2002, 52:9 p.11. ISBN 978 – 972 – 993 – 0935.
Patton KJ, Nitschke RG, Heywood JB: Development and Evaluation of Performance and Efficiency Model for Spark-Ignition Engine. SAE technical paper nr 890836. 1989.
Patton KJ, Nitschke RG, Heywood JB: Development and Evaluation of Performance and Efficiency Model for Spark-Ignition Engine. SAE technical paper nr 890836. 1989.
Patton KJ, Nitschke RG, Heywood JB: Development and Evaluation of Performance and Efficiency Model for Spark-Ignition Engine. SAE technical paper nr 890836. 1989.
Patton KJ, Nitschke RG, Heywood JB: Development and Evaluation of Performance and Efficiency Model for Spark-Ignition Engine. SAE technical paper nr 890836. 1989.
Spiteri: Analysis of engine crankshaft failure. Engineering Failure Analysis. 2005, vol. 16: p. 2333 – 2341.
Sun J, Li B, Zhu S, Miao E, Wang H, Zhao X, Teng Q: Lubrication Performance of Connecting-Rod and Main Bearing in Different Engine Operating Conditions. Chin. J. Mech. Eng. 2019, 32:23.
Taiwo A, Oladeji JT: Automobile workshop practices. Tomio press. 2003, p. 19. ISBN 978-290-204-7.
Takemasa B, Nadolny K: Manufacturing Process of Crankshaft Materials. 2012, 65:9, p.45. ISBN 978-397-305-7.
Velimirović D, Duboka Č, Damnjanović P: Automotive Maintenance Quality of Service Influencing Factors. Tehnicki Vjesnik-Technical Gazette, 2016, 23:5.