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Experimental design of steel bearings and ceramic bearings to find efficient energy consumption

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ABSTRACT

A bearing is a vital machine component that supports shafts, enabling smooth rotation and minimizing friction. The level of friction is determined by the coefficient of friction, which varies based on the bearing material. In this study, we evaluated two types of bearings: steel and ceramic, with the aim of identifying the one with the lowest frictional force and, consequently, the least input power required. To conduct a comprehensive comparison, we performed comparative tests on the Nogogeni Evo V vehicle, analyzing the energy consumption impact of both steel and ceramic bearings. The tests involved measuring the input power of each bearing type at various throttle openings, ranging from 10% to 100%. The results revealed that ceramic bearings exhibited superior energy efficiency compared to their steel counterparts. At all throttle openings, the ceramic bearings consistently demanded lower input power, indicating their higher efficiency. For instance, at 100% throttle opening, the input power for steel bearings was 17,939 watts, while ceramic bearings required only 17,290 watts, representing a 3.6% reduction. Moreover, ceramic bearings achieved higher rotation speeds, with the ceramic bearing rotating at 598 rpm, a 3.5% increase compared to the steel bearing's 577 rpm. Based on these findings, it can be concluded that the implementation of ceramic bearings would significantly enhance the energy efficiency of the Mobil Nogogeni Evo V electric motor. Therefore, for improved performance and reduced energy consumption, we recommend the incorporation of ceramic bearings in the vehicle's design.

INTRODUCTION

The Nogogeni Team of the Institut Teknologi Sepuluh Nopember (ITS) is an electric car team that competed in the Shell Eco-Marathon Asia competition (SEMA). Shell hosts this prestigious energy-efficient automobile competition. In 2017, the Nogogeni Team participated in the Singapore Changi Exhibition Center's Battery Electric class Urban Concept category. At the event, the Nogogeni Team placed third at the Asian level, and in 2018, the Nogogeni Team again placed second. Students of the Department of Industrial Mechanical Engineering, Faculty Vocation ITS developed the "Nogogeni Evo V" automobile through planning, design, simulation, calculation, and manufacture.

Using energy-efficient automobiles is a challenge for the globe today, thus competitions are constantly launched to promote academics' interest in developing electric cars that might be accepted on the global market. The definition of an energy-efficient vehicle is a vehicle whose propulsion takes just a small amount of energy yet can travel a considerable distance. This is strongly related to the vehicle's weight, rolling resistance, drag coefficient, and friction (friction). However, friction is one of the most important factors in this investigation. Friction occurs when two surfaces typically move in opposite directions contact, resulting in resistance.

Continuous friction increases heat and causes these components to deteriorate. The out-of-control friction can harm system components and prevent regular operation. Bearings are thus utilized to avoid excessive friction [1].

The power system is the primary distinction between electric and petrol-engine vehicles. The fuel car system comprises numerous moving components, such as gears, pistons, valves, crankshaft, etc. The working concept of internal combustion is that fuel combustion generates power, with the transmission controlling the process. In contrast, an electric car system employs the vehicle's power, is operated by an electric motor, and has a governor to control its speed.

As is well-known, the greater the number of moving elements in the fuel system, the greater the likelihood of wear and tear and even vehicle damage. In contrast, electric vehicle systems have fewer moving parts, the most essential being the motor shaft's ball bearings. In this regard, the electric vehicle system is better than the conventional gasoline vehicle system. In addition, the performance of electric vehicles is directly influenced by the quality of the bearings on the motor shaft.

A bearing is a component that reduces friction in the engine or other components that move and press against each other [2]–[4]. Bearings are used to maintain or hold moving parts. These items are typically used to support a rotating shaft where friction occurs. Alongside an energy-efficient vehicle, the vehicle must have a low coefficient of friction. To achieve a low frictional force, it is required to use a material with a low friction coefficient and excellent lubrication. If the coefficient of friction is low, then the input power will also be low.

In electric vehicles, conventional motor shaft bearings are generally composed of steel. However, superior alternatives exist. Ceramic bearings, whether hybrid ceramic bearings that combine ceramic balls with steel tracks or pure ceramic bearings, take priority. Silicon Nitride (Si3N4) ceramic bearings will specifically support the electric vehicle industry [5], [6].

Based on the aforementioned issues, the primary objective of this research is to assess the bearing strength by comparing the input power of steel and ceramic bearings on the Nogogeni Evo car across different throttle openings, ranging from 10% to 100%. The main aim is to identify the bearing with a lower input power value, making it suitable for implementation in the Nogogeni Evo V automobile. This, in turn, will lead to reduced energy consumption and enhanced efficiency.

Testing ceramic bearings poses unique challenges, particularly in ensuring compatibility with each electric car being produced. Despite various studies highlighting the advantages of ceramic bearings for advancing electric automobiles, their practical application demands careful consideration. Thus, the research makes a valuable contribution by selecting the most appropriate bearings for the Nogogeni electric car and quantifying the energy-saving potential

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compared to steel bearings. This aspect is crucial for optimizing the car's performance and minimizing energy usage.

METHOD

The test site is at the Nogogeni Workshop, Faculty of Vocation, Department of Industrial Mechanical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya. The testing period runs from May 15, 2022, through May 30, 2022. The following are the tools and materials for testing the Nogogeni Evo V electric car motor bearings.

a. Electric Motor dan Battery

The Nogogeni automobile is powered by a 500-watt, 48-volt Brush DC (Direct Current) electric motor. This electric motor serves as the replacement for the car's engine as a whole. The Nogogeni Evo V automobile uses a Lithium-ion 48-volt 10 Ah battery as the primary source of electrical energy to power the body's electrical system (Controller) and drives motors (electric motor).

b. Controller dan Throttle

As the central processing unit of the Nogogeni vehicle's propulsion system, the controller regulates the amount of output in the form of a positive voltage, which rotates the electric motor in response to foot-operated throttle input. The throttle regulates the magnitude of the input voltage to the electric motor by sending an input signal (maximum 5 volts) to the controller, which then supplies a voltage equal to the input voltage in the form of electric motor rotation. This throttle has 10 throttle opening settings, ranging from 10% to 100% or full throttle. This division is performed with the aid of Arduino software to calculate every 10% throttle opening increase.

c. Joulemeter dan Tachometer

The role of the Joulemeter is to detect and monitor all types of power supply output (battery). A tachometer is an instrument for testing electric motor rotational speed (rpm).

d. Steel and Ceramic Bearings

This study employs German-made "IBC" steel bearings with steel balls and a ceramic separator of size 6002 C3. These bearings have been utilized in Nogogeni cars for four consecutive years in all national and international contests for energy-efficient vehicles (see Figure 1). Moreover, ceramic bearings with total ceramic Zirconia Oxide (ZrO_2) material and size 6002 C5, manufactured in China under the "IMB" brand, were chosen for the 2017 Nogogeni car (see Figure 2). The difference between Figure 1(a) and Figure 1(b) is the use of rubber cover at the top of them. This cover helps the bearing to maintain cleanliness and prolong its life cycle. The same condition applies to Figure 2(a) and Figure 2(b). The cover was expected to keep the minimum friction coefficient value.

e. Motor stand

A motor stand is an auxiliary tool that functions as a holder for an electric motor to ensure that the motor shaft does not revolve throughout the data collection procedure. This motor stand is composed of 2x1-inch metal that is hollow and is joined with rivets.

(a) without rubber cover (b) with rubber cover

Figure 1. Steel bearing with size 6002 C3

(a) without rubber cover

(b) with rubber cover

Figure 2. Ceramic bearing with size 6002 C5

1. Experimental Variables and Parameters

In performing a study, careful and planned experimentation can help find the best reliable results and give confidence in the findings [7]. There are two types of variables in this experiment, namely, independent and dependent variables. An independent variable is a variable whose value is changed so that it affects other variables. The independent variables in this experiment are the types of bearings and rotation based on valve opening. Then, the dependent variable is input current (A), input voltage (V), motor rotation (rpm), initial and final battery voltage (V), and initial and final temperature (℃). Furthermore, the parameter set as a comparison is the required input power for each bearing using Equation (1).

$$P = V \times I \times \mathrm{Cos}\,\emptyset \tag{1}$$

where P is power (Watt), V is defined as voltage (Volt), and $\mathrm{Cos}\,\emptyset$ as power factors.

2. Installation and Test Procedures

Figure 3 depicts the installation system and testing procedure for steel and ceramic bearings on the Nogogeni Evo V electric car motor. Then, Figure 4 displays a variety of real-world test procedures. Those figures show the working process of the electric motor begins with the throttle being opened to a given degree, followed by the electric current entering the electric motor and causing it to rotate at a particular speed. After the rotation has stabilized, the independent variables described in Section 3 are included in the data collection. Following this, the input power and input power loss are calculated.

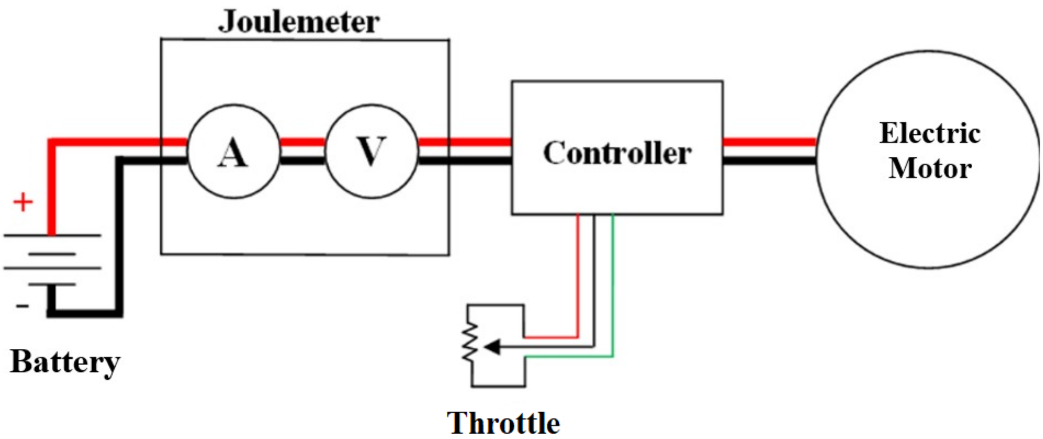

Figure 3. A sequence of test procedures

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Figure 4. A sequence of actual test procedures

3. Testing Procedures

Several steps are required to get the desired bearing testing data for the Nogogeni car propulsion system. These steps are as follows:

1. Prepare the tools and materials needed
2. Ensure tools and materials are in good condition
3. Conduct tests using ceramic bearings with the following steps:
   a. Disassembling the electric motor.
   b. Removing the built-in electric motor bearing with the appropriate tool (see Figure 5).

Figure 5. Removing factory default bearing.

   c. Install ceramic bearings on electric motors with the appropriate tools (see Figure 6 and Figure 7).

Figure 6. The installation process of ceramic bearing.

Figure 7. Installed ceramic bearing

d. Reassemble the electric motor.
e. Organize items in accordance with the installation and testing plan
f. Give changes of throttle opening between 10 and 100 percent.
g. Hold each throttle opening until a stable number is obtained.
h. Obtain test data and outcomes.

4. After that, conduct the test with steel bearings.
   a. Disassemble the electric motor.
   b. Remove the ceramic bearing with the appropriate tool (see Figure 8).

Figure 8. Removal of ceramic bearings

c. Install steel bearings on electric motors using the proper tools (see Figure 9 and Figure 10).

Figure 9. The process of installing steel bearings (steel)

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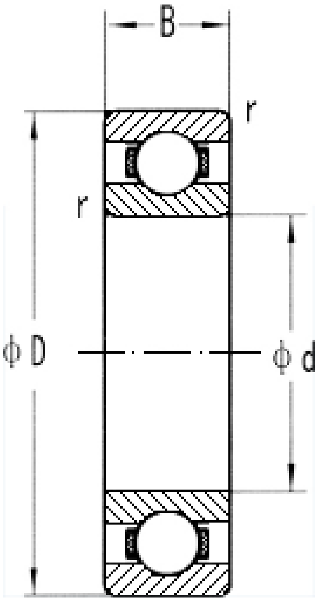
Figure 10. Installed steel bearings

   d. Reassemble the electric motor.
   e. Organize items following the installation and testing plan
   f. Give changes of throttle opening between 10 and 100 percent.
   g. Hold each throttle opening until a stable number is obtained.
   h. Obtain test data and outcomes.
5. Compare the test results for both steel and ceramic bearings
6. Conclude with a conclusion.

RESULTS AND DISCUSSION

This section outlines the findings of input power testing on ceramic bearings and steel bearings for the Nogogeni Evo V electric car's motor and the calculations relating to those results. Figure 11 illustrates the dimensions and quantity of the installed bearings. The electric motor of the Nogogeni Evo-V car is equipped with "single-row deep groove ball bearings". A succession of balls rolls within the bearing's groove. This bearing is the most basic rolling bearing commonly seen in machine tools. This section describes the gathering of data (current and voltage) that inputs the electric motor when ceramic bearings and steel bearings are used.



D (outside diameter) = 32 mm
d (inside diameter) = 15 mm
B (width) = 9 mm
r (minimum radius) = 0.3 mm

Figure 11. Bearing dimensions

1. Data Collection

Data was collected by comparing the bearings installed on the Nogogeni Evo V's electric motor, which serves as the vehicle's prime mover. Through a comparison of the input power of steel and ceramic bearings installed on an electric motor. During the test, no load was applied to the electric motor, which was supported by a motor stand for stability.

The data in Table 1 and Table 2 represent the results of testing electric motors with steel and ceramic bearings after holding the throttle open every 10 percent of the throttle opening for 5 minutes. Under each electric motor test's 10% throttle opening conditions, the battery is fully charged to 54.5 volts.

Table 1. Test data using steel bearings

Throttle Opening (%)	Input Current (A)	Input Voltage (V)	Motor rotation (rpm)	Initial Voltage (V)	End Voltage (V)	Initial Temp (°C)	End Temp (°C)
10	0.02	5.85	0	54.5	54.5	32	32
20	0.04	12.80	30	54.5	54.5	32	32.2
30	0.08	19.50	149	54.5	54.5	32	32.4
40	0.10	27.05	251	54.4	54.4	32	32.6
50	0.14	33.70	333	54.5	54.5	32	32.9
60	0.17	40.00	429	54.4	54.4	32	33.3
70	0.23	43.05	509	54.4	54.4	32	33.8
80	0.27	47.80	576	54.5	54.5	32	34.2
90	0.32	49.10	598	54.5	54.5	32	34.9
100	0.32	53.20	598	54.5	54.5	32	35

Table 2. Test data using ceramic bearings

Throttle Opening (%)	Input Current (A)	Input Voltage (V)	Motor rotation (rpm)	Initial Voltage (V)	End Voltage (V)	Initial Temp (°C)	End Temp (°C)
10	0.02	5.90	0	54.5	54.5	32	32.0
20	0.06	13.00	29	54.5	54.5	32	32.2
30	0.08	21.40	144	54.5	54.5	32	32.4
40	0.12	27.50	243	54.4	54.4	32	32.7
50	0.16	33.10	323	54.4	54.4	32	33.1
60	0.22	38.40	401	54.5	54.5	32	33.6
70	0.26	43.00	465	54.5	54.5	32	34.2
80	0.31	47.60	534	54.4	54.4	32	34.7
90	0.33	50.70	577	54.5	54.5	32	35.2
100	0,33	53.50	577	54.5	54.5	32	35.3

2. Input Power Calculation

This section describes the findings from calculating the motor's input power when steel and ceramic bearings are used at particular throttle openings. Table 3 compares the input power and electric motor rotation of steel and ceramic bearings for electric motors. Meanwhile, Figure 12 depicts a comparison between input power (Watt) and motor rotation (Rpm) for steel and ceramic bearings, based on Table 3.

Figure 12 (a) demonstrates that the power input for ceramic bearings is less than steel bearings for various throttle openings. Figure 12 (b) indicates that at the same throttle opening, the resultant motor rotation is greater with ceramic bearings than steel bearings. This is because ceramic bearings have a lower friction coefficient than steel bearings. Due to the smaller friction coefficient, the rotational force will be reduced. If the force is diminished, the input power will also be diminished. Consequently, the energy required to power the motor is used more efficiently. Less energy is the optimal solution for electric cars, a current trend in sustainable global development [8].

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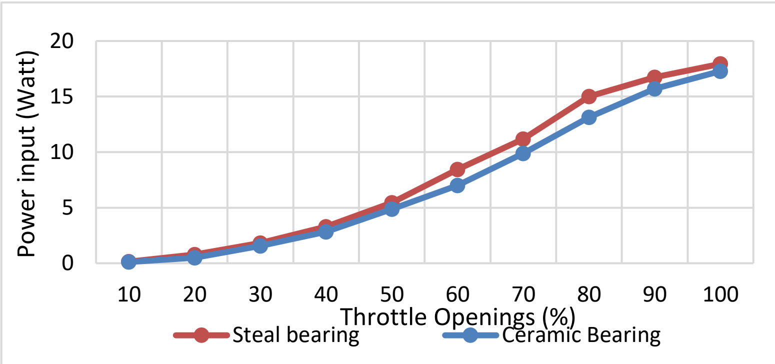
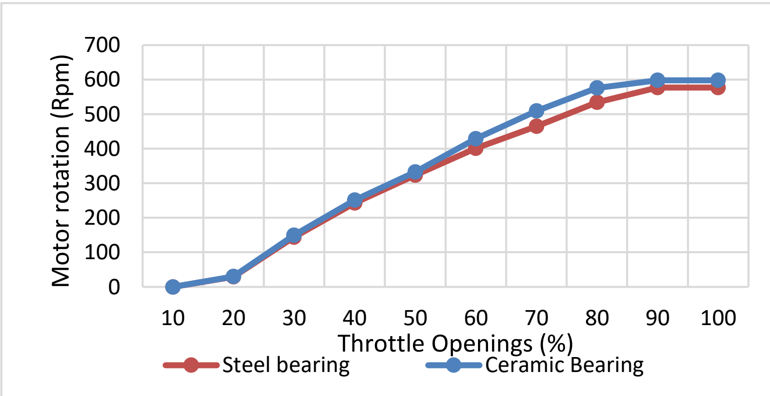
Table 3. Comparison of input power and electric motor rotation for steel bearing and ceramic bearing

No.	Throttle Openings (%)	Steel bearing		Ceramic bearing	
		P (Watt)	n (Rpm)	P (Watt)	n (Rpm)
1.	10	0.148	0	0.117	0
2.	20	0.780	29	0.512	30
3.	30	1.823	144	1.560	149
4.	40	3.306	243	2.840	251
5.	50	5.461	323	4.886	333
6.	60	8.459	401	7.000	429
7.	70	11.180	465	9.901	509
8.	80	15.000	534	13.145	576
9.	90	16.731	577	15.712	598
10.	100	17.939	577	17.290	598



(a) Input power vs. Throttle openings



(b) Motor rotation vs. Throttle openings

Figure 12. Comparison between steel bearing and ceramic for power input and motor rotation

3. Lubrication of Rolling Bearings

In addition to using bearings with a low friction coefficient, lubricating oil with the proper viscosity can reduce power input [9]. The exact viscosity depends on the inner diameter, the rotating speed of the bearings, and the operating temperature. This section therefore addresses the lubrication of rolling bearings. In bearings, lubrication is essential for reducing frictional forces, wear rates, and heat generation [2], [3], [10]–[12].

The needed viscosity of lubricating oil to lubricate steel bearings can be calculated by measuring the bearings' temperature. This temperature reading was collected with an infrared thermometer. Then, based on Figure 13, the value of DN is obtained by multiplying the value of the inside diameter (D) and the rotation (N). Then, DN value can be inputted into the viscosity-based lubricating oil selection chart (see Figure 13) to determine the lubricating oil viscosity value based on the intersection of the inside diameter value line multiplied by rotation and the working temperature line (°F).

For instance, multiplying an interior diameter (D) value of 32 mm by a maximum rotation value (n) of 577 rpm yields a Dn value of 18,464 mm. rpm. This value will be plotted on the lubricating oil selection chart, shown by the green line. In addition, the temperature of 95°F is mapped on the graph and represented by a blue line. The junction of the green and blue lines will produce a point that may be plotted on the viscosity line for lubricating oil, shown by the red line. Based on the graph, the viscosity value of lubricating oil is 130 SUS at 100°F.

On a 100°F basis, viscosity 130 SUS can be translated to Society Automotive Engineer (SAE) units. If a horizontal line (red color) is formed from the conversion table (Figure 14) on the viscosity value of 130 SUS lubricating oil with a base of 100°F, then the optimum lubricating oil viscosity value for steel bearings is SAE 10 W.

The findings of electric motor testing can be summarized as follows. The results of electric motor testing with steel and ceramic bearings yielded data on input power and electric motor rotation. When the throttle is fully opened and tested for 5 minutes, the electric motor's input power with steel bearings is 17,939 watts and 17,290 watts with ceramic bearings. The maximum rotation of the electric motor when using steel bearings is 577 rpm, and it is 598 rpm when using ceramic bearings. Ceramic bearings have a higher rotation despite having a lower input power.

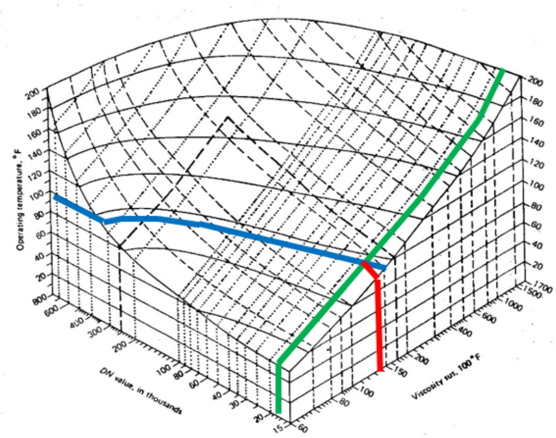


Figure 13. Lubricating oil selection chart based on viscosity

Furthermore, the working temperatures of steel bearings and ceramic bearings are the same when the throttle opening is 10% -30% and begin to differ when the throttle opening is 40% - 100%. Ceramic bearings have a lower maximum working temperature than steel bearings, with a maximum working temperature of 35°C vs 35.3°C for steel bearings. The difference in bearing material affects the heat generated due to friction in the bearing. As a result, the proper lubricating oil is utilized, namely SAE 10 W lubricating oil.

4. Theoretical Analysis and Discussion

The automotive sector is undergoing a transition towards electric vehicle technology, driven primarily by the need for cleaner energy and reduced reliance on fossil fuels. The utilization of bearings per vehicle is expected to decrease with the introduction of electric vehicles. Khaire [13] explores the implications of electric vehicles on the bearing industry and discusses the new technological demands necessary for the successful development of EV bearings. Key technical requirements for EV bearings include improved bearing lifespan, enhanced reliability, compact size, integration of smart sensor capabilities, optimized friction and noise reduction, as well as considerations for vibrations and harsh operating conditions. Special attention must also be given to lubrication and sealing processes. Surface engineering techniques and the application of specialized coatings offer potential to expand the range of

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bearing applications and optimize the cost of bearings for electric vehicles. However, it is important to address challenges such as electrical pitting and lubricant burning, which can lead to internal contamination and potentially reduce the lifespan of bearings. Bearing engineers must adapt their expertise to meet the new requirements posed by electric vehicles.

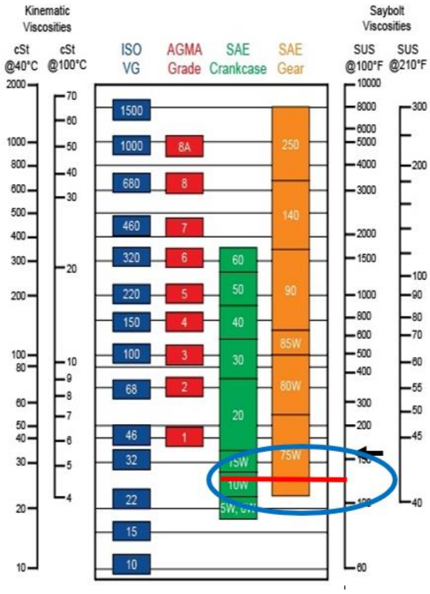

Figure 14. Lubricating oil selection chart based on viscosity

In today's context, there is a significant focus on finding ways to enhance the efficiency of electric vehicles. However, the ultimate goal of electric mobility, in addition to environmental concerns, is to ensure affordability. Similar to conventional cars, the cost of an electric vehicle is directly linked to its power. Every aspect of an electric car is optimized for maximum energy conservation. A crucial requirement for the advancement of electric vehicles is the utilization of well-designed electric motors as a key component of the electromechanical system. Currently, induction motors are predominantly used in electric vehicles due to their superior efficiency and well-known benefits. The motor under investigation is suitable for quick and straightforward conversions of numerous compact front-wheel-drive vehicles by replacing their engines. Rachev et al. [14] focuses on evaluating the combined impact of modifying the equivalent circuit parameters and the total moment of inertia on the power losses in the dynamic operational modes of a compact electric car drive. The study employs an appropriate mathematical model of the electromechanical system and presents the results in both tabular and graphical formats. Relevant conclusions have been drawn based on the findings. Apart from analysis, the developed model can also aid in solving the inverse problem by facilitating the development of electric motors and control systems with parameters that meet specific user-defined requirements.

In addition, Migal et al. [15] examines the impact of various factors such as bearing accuracy class, rotational speed, load, clearances, and fits on the vibration levels of electric motor bearing units. It proposes methods to reduce vibrations originating from mechanical sources. The maximum allowable vibration levels for asynchronous motors are determined to be 40 dB at 5 Hz and 80 dB at 10,000 Hz. The influence of increased rotational speed and load on the vibration levels of bearing units is analyzed, and potential measures to decrease vibrations while maintaining optimal bearing preload on the shaft journal are identified. The research reveals that the clearance between the cap and the bearing, when fixed in the housing (primer), does not guarantee the consistency of the bearing unit assembly, leading to significant variations in vibration levels compared to rigid and elastic fixation methods. The findings of this study are applicable to all types of traction electric motors.

Moreover, transportation is a significant contributor to various environmental challenges, including greenhouse gas (GHG) emissions and resource depletion. In the European Union, light-duty vehicles account for approximately 10% of total energy consumption and air pollutants. Consequently, there is an urgent need for improved fuel/energy efficiency in both conventional and electric cars. Industrial and research communities have been actively proposing innovative solutions to address this issue. Del Pero [16] conducts a comparative Life Cycle Assessment (LCA) of Internal Combustion Engine (ICE) vehicles and electric vehicles. The assessment follows a comprehensive "from cradle-to-grave" approach, considering the entire life cycle of the vehicles, including the production, use, and end-of-life stages. Primary data is predominantly used for the inventory, and a broad range of impact categories related to human and ecosystem health are considered. The environmental profiles of different vehicle configurations are evaluated, and the key environmental issues affecting both conventional and electric cars are identified and critically examined. The study also investigates the impact dependence on life cycle mileage for both propulsion technologies and determines the break-even point for the environmental viability of electric cars, taking into account various electricity sources during the use phase. Furthermore, the analysis includes a comparison of GHG emissions with the findings from previous LCA studies.

The past decade witnessed a significant surge in the popularity of electric transportation, supported by extensive government assistance. This resulted in a remarkable increase in annual electric vehicle (EV) sales worldwide, rising from a mere 2,000 to over 753,000 units within the span of ten years. Numerous countries and private enterprises have high expectations for electric transport, envisioning the imminent displacement of internal combustion engines (ICE). However, Kapustin and Grushevenko [17] reveals that as of 2018, EVs are still unable to compete on an equal footing with conventional cars. Nonetheless, if governments and automobile manufacturers continue their current pace of development, true competitiveness between ICE and electric vehicles could be achieved by 2035, even in a low oil-price environment. Our calculations indicate that by 2040, depending on the scenario, EVs could capture an 11-28% share of the global road transport fleet. Consequently, this would lead to an additional increase in global electricity consumption ranging from 11% to 20%. Nevertheless, a major challenge lies in adapting the power grid to accommodate the growing demand peaks resulting from EV charging patterns. To maintain the trajectory towards "green" energy, global leaders in EV adoption must intensify their efforts in developing and implementing energy storage technologies. Failure to do so could result in a rise in fossil fuel consumption as the proliferation of electric cars expands.

Recent global interest in achieving greater energy efficiency and promoting environmental sustainability has led to a focus on improving transportation systems and industrial practices. Approximately one-fifth of the world's energy consumption is attributed to friction, with one-third of energy used in transportation dedicated to overcoming friction. However, significant progress has been made in the development of all-electric vehicles powered by advanced batteries, offering a cleaner and more sustainable future for transportation. Holmberg and Erdemir [18] provides a brief overview of the energy efficiency and environmental impacts associated with current transportation, industrial, and residential systems, highlighting how friction and wear losses in moving mechanical parts significantly impact overall efficiency. Additionally, it discusses recent advancements in materials, lubricants, and design modifications that could potentially reduce energy losses by 18-40%, primarily due to friction and wear. These improvements could result in energy savings of up to 8.7% of global energy consumption and 1.4% of the gross national product (GNP). Furthermore, the article calculates the energy consumption and friction losses in battery-powered electric passenger cars, demonstrating the benefits of electric vehicles with an average total energy usage that is 3.4 times lower compared to combustion engine-powered cars. When the electricity for electric cars is sourced from renewable energy, the CO_2 emissions are 4.5 times lower compared to combustion engine cars. Transitioning from fossil fuels to renewable energy sources has the potential to reduce energy losses caused by friction in energy production by more than 60%.

Last but not least, the rise of electric vehicles drivers a significant shift away from conventional motor vehicles. The primary motivations behind this transition are the urgent need to reduce polluting emissions from engines and reduce dependence on costly fuels. By the end

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of 2016, the global number of electric vehicles had surpassed two million, reflecting the increasing acceptance of electric vehicles. This acceptance can be attributed to various factors, such as technological advancements, improved storage capacity of traction batteries at reduced costs, and the proliferation of public and government charging infrastructure. The two prominent electric vehicle technologies currently in the spotlight are battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). Pandey et al. [19] provides an overview of these different electric vehicle technologies, outlining their characteristics, limitations, and the challenges associated with their widespread adoption as replacements for conventional vehicles.

In this new era, electric vehicles have garnered significant attention as environmentally friendly modes of transportation, capturing the interest of sellers, buyers, and researchers alike. Consequently, extensive and thorough studies have been conducted, focusing on various aspects such as battery consumption, infrastructure development, charging point availability, and associated challenges. This article considers the obstacles and benefits that the world will encounter upon the full-scale adoption of electric vehicles. It successfully presents an overview of electric vehicle aspects, encompassing government policies, charging methods, key technologies, charging impacts, and potential solutions to related issues in a concise manner. Taking into account the current electric vehicle landscape, this brief report compiles essential facts pertaining to the emergence of electric vehicles.

CONCLUSION

Based on the results of the tests and calculations performed on the Mobil Nogogeni Evo V electric motor to compare the steel and ceramic bearings, the following conclusions are ceramic bearings have a lower input power than steel bearings; at 100% valve opening, the input power of ceramic bearings is 17,290 Watt, and the input power of steel bearings is 17,939 Watt, resulting in a 3.618% decrease in input power. Then, ceramic bearing rotation is greater than steel bearing rotation; with 100% valve opening, ceramic bearing rotation is 598 rpm, and steel bearing rotation is 577 rpm, resulting in a 3.51% increase in rotation. Next, reducing average input power by 14.51%, increasing average rotation by 4.588%. Then, the steel bearing requires a lubricant [20]. Generally, the lubricant viscosity that can be used is 139 SUS-100oF or SAE 10 W. This research proposes some recommendations are all-steel bearings in the Nogogeni Evo V car should be replaced with ceramic bearings to conserve energy depending on the type of car, including energy-efficient cars. More research is needed to compare the life of steel and ceramic bearings. Another option for measuring input power is using dyno test equipment.

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REFERENCES

[1] S. Pan, D. Wang, and W. Huang, “A novel small motor measurement system based on ultrasonic bearings,” Meas., vol. 168, Aug 2020, doi: https://doi.org/10.1016/j.measurement.2020.108307.

[2] B. K. Ginty, “Bearing materials for small electric motors,” Tribol. Int., vol. 15, no. 2, pp. 85–88, 1982, doi: https://doi.org/10.1016/0301-679X(82)90057-3.

[3] W. Liu, “The prevalent motor bearing premature failures due to the high frequency electric current passage,” Eng. Fail. Anal., vol. 45, pp. 118–127, 2014, doi: https://doi.org/10.1016/j.engfailanal.2014.06.021.

[4] M. Herrmann, Ceramic Bearings and Seals, Second Edi. Elsevier Inc., 2013, doi: https://doi.org/10.1016/B978-0-12-385469-8.00017-4.

[5] J. Oliver, G. Guerrero, and J. Goldman, "Ceramic bearings for electric motors," in IEEE Cement Industry Technical Conference (Paper), pp. 1–11, 2015, doi: 10.1109/CITCON.2015.7122604.

[6] A. Gabelli and G. E. Morales-Espejel, "A model for hybrid bearing life with surface and subsurface survival," Wear., vol. 422–423, pp. 223–234, 2019, doi: https://doi.org/10.1016/j.wear.2019.01.050.

[7] M. N. A. Rahman, N. S. M. Zubir, R. A. C. Leuveano, J. A. Ghani, and W. M. F. Wan Mahmood, "Reliability study of solder paste alloy for the improvement of solder joint at surface mount fine-pitch components," Materials, vol. 7, no. 12, pp. 7706–7721, 2014, doi: https://doi.org/10.3390/ma7127706

[8] M. A. Hannan, M. M. Hoque, A. Mohamed, and A. Ayob, "Review of energy storage systems for electric vehicle applications: Issues and challenges," Renew. Sustain. Energy Rev., vol. 69, pp. 771–789, 2017, doi: https://doi.org/10.1016/j.rser.2016.11.171.

[9] H. K. D. H. Bhadeshia, "Steels for bearings," Prog. Mater. Sci., vol. 57, no. 2, pp. 268–435, 2012, doi: https://doi.org/10.1016/j.pmatsci.2011.06.002.

[10] A. Hermawan, I. B. Rahardja, M. Y. Syam, H. Sukismo, and N. Patah, "Analysis of Viscosity of Lubricating Oil on Generator Machine Working Hours at KP. Macan Tutul 4203," J. Appl. Sci. Adv. Technol., vol. 1, no. 3, pp. 69–74, 2019, [Online]. Available: https://jurnal.umj.ac.id/index.php/JASAT/article/view/4312/3086

[11] A. Xu, P. Tian, H. Li, S. Wen, and Y. Tian, "Extreme pressure lubrication between ceramic and bearing steel with liquid metal," Tribol. Int., vol. 174, no. July, p. 107797, 2022, doi: https://doi.org/10.1016/j.triboint.2022.107797.

[12] H. K. Danielsen et al., "Accelerated White Etch Cracking (WEC) FE8 type tests of different bearing steels using ceramic rollers," Wear, vol. 494–495, 2022, doi: https://doi.org/10.1016/j.wear.2021.204230.

[13] M. V. Khaire, "Electrical vehicles' bearings: technological impact, applications and requirements," Int. J. Elect. and Hybrid Veh., vol. 10, no. 4, 2018, doi: https://doi.org/10.1504/IJEHV.2018.098093.

[14] S. Rachev, D. Stefanov, L. Dimitrov, and D. Koeva, "Evaluation of Electric Power Losses of an Induction Motor Driving a Compact Electric Vehicle at Change of Parameters and Loads," Electric Vehicles International Conference & Show, 2019, doi: 10.1109/EVICS.2019.8784156.

[15] V. Migal, A. Lebedev, M. Shuliak, E. Kalinin, S. Arhun, and V. Korohodskyi, "Reducing the vibration of bearing units of electric vehicle asynchronous traction motors," J. of Vib. and Control, Vol 1-9, 2020 doi: https://doi.org/10.1177/1077546320937634

[16] F. D. Pero, M. Delogu, and M. Pierini, "Life cycle assessment in the automotive sector: a comparative case study of internal combustion engine and electric car", in AIAS 2018 International Conference on Stress Analysis, Procedia Struct. Integr., vol. 12, pp. 521-537, 2018, doi: https://doi.org/10.1016/j.prostr.2018.11.066

[17] N. O. Kapustin and D. A. Grushevenko, "Long-term electrical vehicles outlook and their potential impact on electric grid, Energy policy, vol. 137, 2020, doi: https://doi.org/10.1016/j.enpol.2019.111103

[18] K. Holmberg and A. Erdemir, "The impact of tribology on energy use and CO2 emission globally and in combustion engine and electric cars," Tribol. Int., vol. 135, pp. 389-396, 2019, doi: https://doi.org/10.1016/j.triboint.2019.03.024

[19] A. Pandey, S. Manocha, and P. Saini, "A study on an automobile revolution and future of electric cars in India," Int. J. Manage., vol. 11, no. 3, pp. 107–113, 2020, doi: 10.34218/IJM.11.3.2020.013.

[20] L. I. Farfan-Cabrera, "Tribology of electric vehicles: A review of critical components, current state and future improvement trends," Tribol. Int., vol. 138, pp. 473–486, 2019, doi: https://doi.org/10.1016/j.triboint.2019.06.029.

 10.12928/ijio.v4i2.7137