Düzce University Journal of Science & Technology, 11 (2023) 1296-1302

Düzce University
Journal of Science & Technology

Research Article

Starter Selection for Diesel Engines

Şenol GÜLGÖNÜL [a,*], Nedim SÖZBİR [b], Osman DUR [c]

[a] *Electrical and Electronics, Faculty of Engineering, Ostim Technical University, Ankara, TÜRKİYE*
[b] *Rector, Duzce University, Düzce, TÜRKİYE*
[c] *İleri Teknolojiler Bölümü, Fen Bilimleri Enstitüsü, Gazi Üniversity, Ankara, TÜRKİYE*
* *Sorumlu yazarın e-posta adresi: senolgulgonul@gmail.com*
DOI: 10.29130/dubited.1210015

ABSTRACT

Starter selection is a critical decision in diesel engine design. The starter performance curves are generally accepted in the industry, with current on the horizontal axis and power, volts, speed and starter torque on the vertical axis. In this way, it is not possible to compare the starter performance curves with the engine friction force curve. In this study, a method has been developed for the selection of suitable starter for diesel engines. With the developed method, the starter performance curve is converted and the engine friction curve is shown on the same graph. With this method, it can be easily understood whether the starter is suitable for a diesel engine. In addition, possible problems that may be encountered during cold start-up can be foreseen. The developed method uses actual performance measurements given by the starter manufacturer. On the engine side, if there is an existing engine, engine friction test results are used. If the engine is in the design phase, the friction force results obtained by simulation are used.

Keywords: *Diesel engine, Engine friction, Starter, Cranking*

Dizel Motorlarda Marş Motoru Seçimi

ÖZ

Marş motoru seçimi, dizel motor tasarımında kritik bir karardır. Marş motoru performans eğrileri endüstride genel kabul gören şekli ile yatay eksende akım, dikey eksende ise güç, volt, hız ve marş motoru torku olacak şekildedir. Bu şekilde marş motoru performans eğrilerinin motor sürtünme kuvveti eğrisi ile karşılaştırılması mümkün olmamaktadır. Bu çalışmada, dizel motorlar için uygun marş motoru seçimine yönelik bir yöntem geliştirilmiştir. Geliştirilen yöntem ile marş motoru performans eğrisi dönüştürülerek, motor sürtünme eğrisi aynı grafik üzerinde gösterilmektedir. Bu yöntem ile marş motorunun dizel motora uygun olup olmadığı kolaylıkla anlaşılabilmektedir. Ayrıca soğuk çalıştırma sırasında karşılaşılabilecek olası problemler öngörülebilmektedir. Geliştirilen yöntem, marş motoru üreticisi tarafından verilen gerçek performans ölçümlerini kullanır. Motor tarafında ise mevcut bir motor varsa motor sürtünme testi sonuçları kullanılır. Eğer motor tasarım aşamasında ise simülasyon ile elde edilen sürtünme kuvveti sonuçları kullanılır.

Anahtar Kelimeler: *Dizel motor, Motor sürtünme kuvveti, Marş motoru, Krank*

Received: 25/11/2022, Revised: 15/02/2023, Accepted: 28/02/2023

I. INTRODUCTION

Starter selection is mission critical in diesel engine design. The starter needs to bring the engine to cranking speed (typically 250 rpm) at which injection will begin, both in normal weather conditions and in cold weather. Besides, certain cranking speeds must be reached in order to establish the minimum rail pressure (typically 500 bar) at which injection can begin. A ready-made starter is generally used in diesel engine design. Therefore, the characteristics of the starter are known from the performance curves. In order to select the starter suitable for the developed diesel engine, the engine friction curve and the starter performance curves should be compared. In the diesel engine design phase, this comparison can only be made with simulation.

Stribeck curve defines engine friction in three regions: boundary, mixed and hydrodynamic [1]. Testing of friction is an important part of each combustion engine's development program and there are several measurement methods [2]. In addition to measurements, simulation methods that give similar results have also been developed [3]. Engine friction significantly increases in cold start and reduces cranking speed [4].

Starter manufacturers give information about the product's performance curve and displacement volume (litre) range of suitable engines. But this is a wide range and the design cannot be built on it. For example, Iskra 24V AZG model starter is given as suitable for 7 to 17 litre displacement [5]. For this reason, analyses based on measurement results can be effectively used to select the appropriate starter in engine design [6]. In the guides on practical starter selection, it is recommended to test the selected starter with the engine [7].

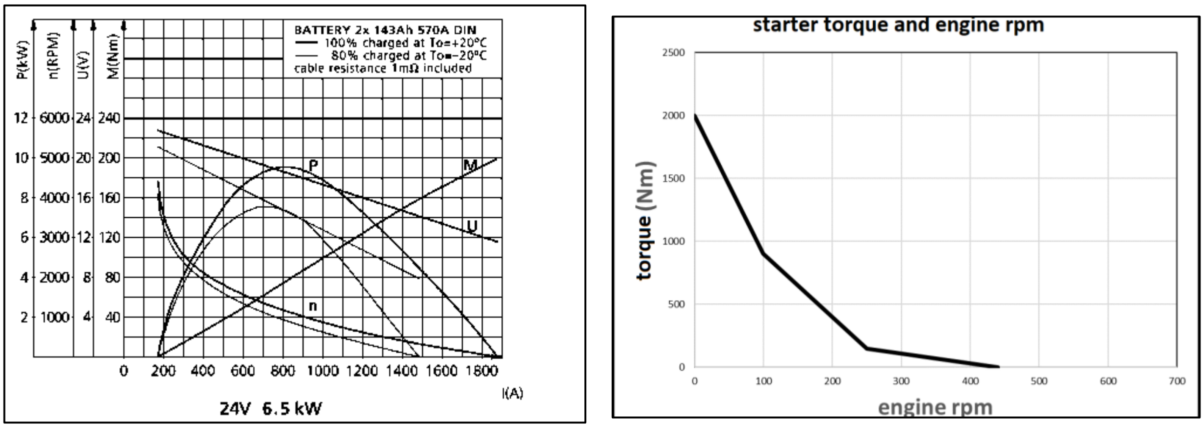
In another study, Saber commercial simulation software was used for diesel engine and starter simulation, and simulation and test results were compared [8]. While the engine cranking speed reached an average value of 250 rpm at +22˚C in the study, it remained at 150 rpm at -19˚C operation. Similarly, in our study, the engine may be stuck at lower speeds in cold start. In a similar study, while the engine cranking speed reaches an average of 200 rpm at +20˚C, it remains at 90 rpm at -18˚C [9].

The starter performance curves are given as current on the x-axis and power, rpm, torque and voltage values on the y-axis in accordance with ISO 8856. The friction curve of the engine is measured as torque on the y-axis and engine rpm on the x-axis. This makes it difficult to compare whether the relevant starter is suitable for the engine. In this study, a method that combines the starter performance and the engine friction curves is proposed. With this method, it can be easily understood whether the starter is sufficient for a diesel engine. The usability of the proposed method is shown with the simulation results.

II. MODEL DEVELOPMENT

A. CONVERSION OF STARTER PERFORMANCE CURVE

Generally accepted style of starter performance curve is given with current on x-axis. Starter power (kW), starter rpm, voltage (V) and torque (Nm) values are shown on y-axis. An example performance curve for Iskra AZG 24V model starter is shown in Figure 1 (a) [5].



(a) (b)

Figure 1. ***(a)*** *Starter curve (Courtesy of Iskra Avtoelektrika)* ***(b)*** *Converted starter curve*

Since engine friction curves are given as engine rpm in x-axis, this type of starter curves are not suitable to easily compare starter torque to engine friction. We converted starter performance curve to the torque applied to the engine on Y-axis and engine rpm on X-axis by multiplying starter to flywheel gear ratio as shown in Figure 1 (b). The engine rpm-starter torque curve was created by combining the starter rpm-current data with the starter current-torque data. Starter rpm-current and starter current-torque curves transferred into Simulink matrices. Multiplication of rpm-current and current-torque matrices yields rpm-torque curve as shown in Figure 4. Number of teeth in starter pinion is typically 10,11,12. Flywheel ring gear generally has 113, 120, 124 teeth. This yields around 1/10 gear ration. The gear ratio (typically 10) of the starter pinion to the flywheel must also be taken into account. The starter torque is multiplied by the gear ratio to get the torque applied to the engine. Similarly, the starter rpm is divided to gear ratio to get engine rpm. All these operations are shown on the Simulink model in Figure 4.

Stribeck curve (Figure 2.) explains engine friction in three regions: boundary, mixed and hydrodynamic [1]. In the first region engine is in stall and starter starts to rotate. As soon as the flywheel starts to rotate, the oil pump mechanically connected to the flywheel starts pumping oil and friction is reduced. As the engine starts to rotate, the friction force increases proportionally with the engine rpm. Stribeck curve allows us to represent friction curve of the engine in a piecewise linear model. Engine friction is usually measured above idle speed and is linearly proportional to engine speed at speeds above idle speed [10]. This part corresponds to the hydrodynamic friction region of the Stribeck curve. Friction at low speeds is simulated piecewise linearly to the Stribeck curve. The engine friction curve used in the study was formed theoretically in this way.

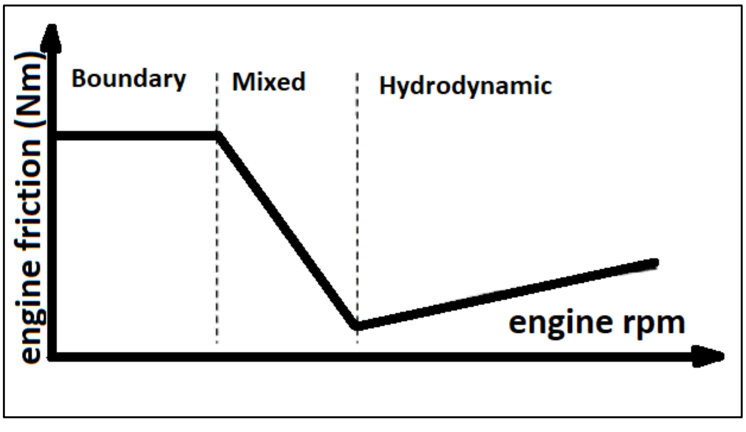


Figure 2. *Stribeck Engine Friction Curve*

Now we can show the starter torque curve and the engine friction curve on the same graph (Figure 3). This allows us to better compare and analyse possible problems. The starter torque curve is above the engine friction curve in the normal operating conditions and curves intersect above 250 rpm. Typical minimum cranking rpm where injection starts is 250 rpm in diesel engines.

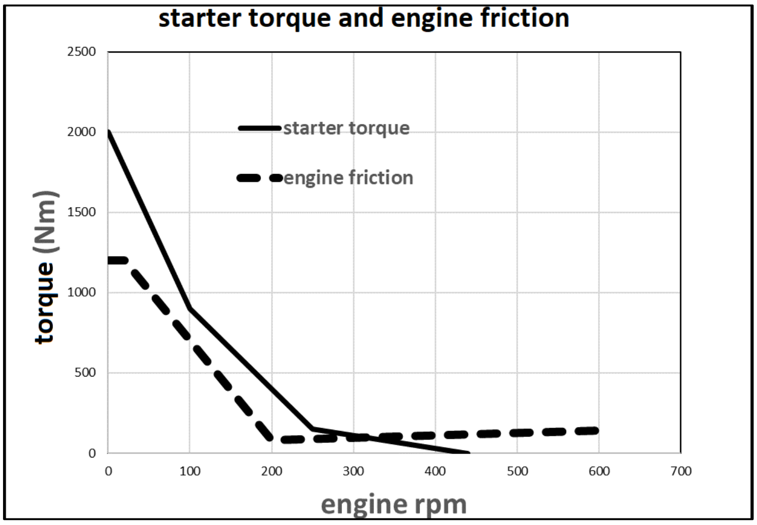


Figure 3. *Starter torque and engine friction curves*

B. ENGINE CRANKING MODEL

Net torque applied to the engine is starter torque (T) multiplied with gear ratio (k) reduced by friction of the engine. This can be expressed as

$$k \times T - F = I \times \frac{dw}{dt} \qquad (1)$$

where w is angular velocity and I is the inertia of the engine. The engine rotation (rpm) can be deducted by taking the integral of angular velocity and converting angular velocity to rpm

$$rpm = \frac{60}{2\pi} \times \int \frac{(k \times T - F)}{I} \times dt \qquad (2)$$

Equations (1), (2) and curve conversion has been modelled in Simulink (Figure 4.). Since we are using real numerical measurement data of starter torque and engine friction, the problem must be solved numerically. We used Iskra 24V AZG starter performance parameters. The engine used in simulation is a theoretical 6-cylinder diesel engine with 2.5 kgm2 inertia.

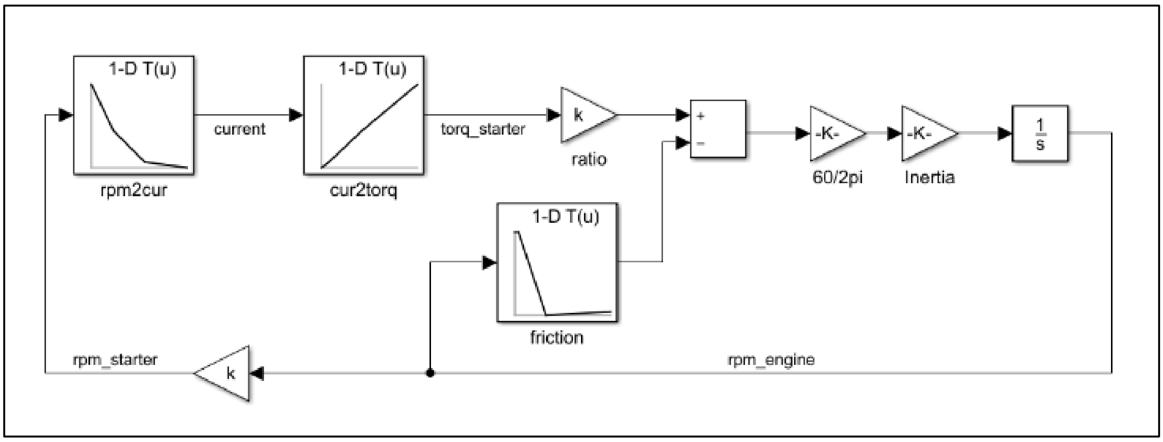


Figure 4. *Diesel engine cranking model*

In normal conditions where starter torque is above the engine friction as shown on Figure 3 starter can rotate the flywheel above minimum cranking speed (typically 250 rpm). Simulink output in Figure 5 shows that starter brings the engine rpm up to 316 rpm which is the intersection point of torque and friction curves.

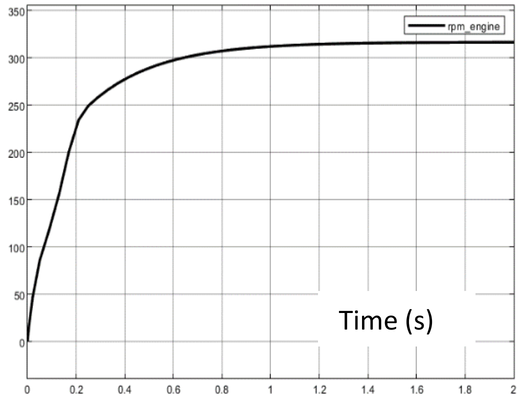
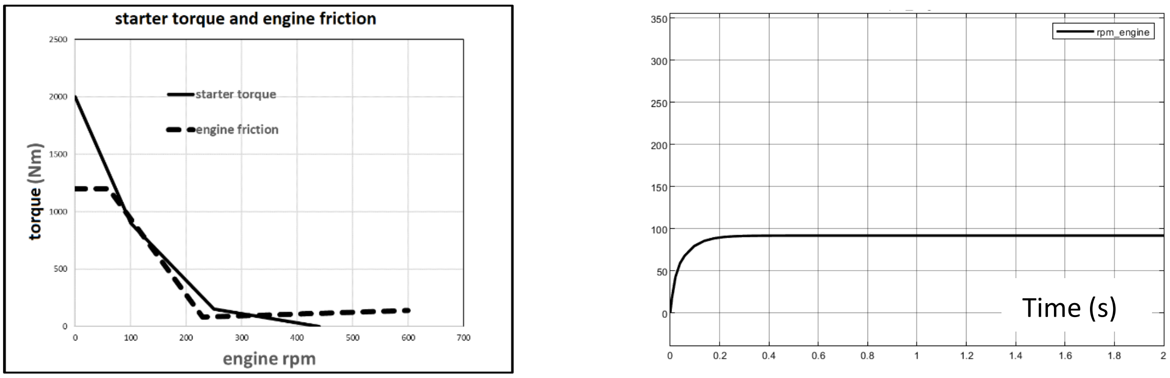


Figure 5. *Diesel engine cranking rpm in normal behaviour*

There may be various cranking problem scenarios especially faced at cold cranking. In the first scenario starter cannot overcome the stall friction of the engine and cannot turn the flywheel at all. In this case starter will be locked at stall condition and will draw high current. This high current can burn the starter and shall not be allowed above a few seconds.

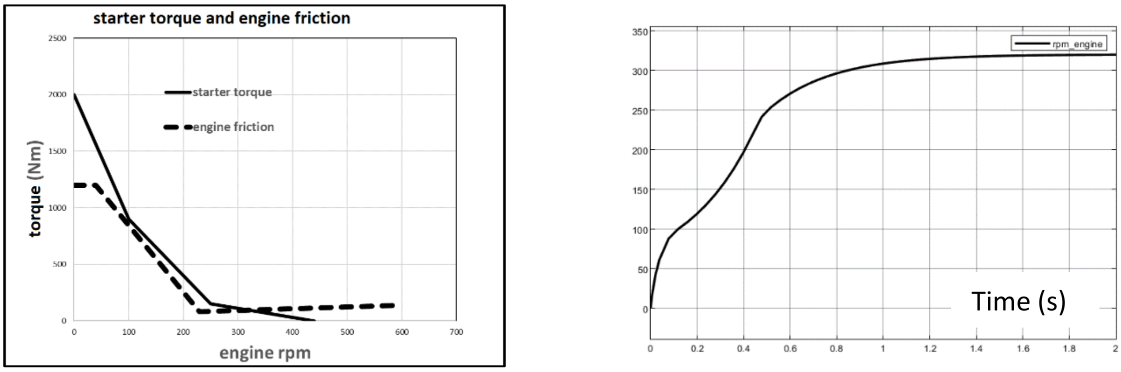
In the second possible scenario, the starter cannot reach the cranking speed and the engine is stuck at low rpm. This may happen if starter torque and engine friction curves intersect at low rpm as shown at Figure 6 (a). In the simulated example, engine speed is stuck at 91 rpm as shown on Figure 6 (b) and cannot reach minimum cranking speed (typically 250 rpm). Thus, injection will not start.



(a) **(b)**

Figure 6. (a) *Starter torque intersects at lower rpm* ***(b)*** *Engine speed is stuck at lower rpm*

The cranking engine speed curve in normal weather conditions can warn us about possible problems that we may encounter in cold weather conditions. In this case, starter torque curve is still above engine friction but gets closer at low rpm as seen on Figure 7 (a). This causes a noticeable curvature in engine cranking curve on Figure 7 (b). While this engine is starting normally in mild temperature conditions, will probably stick around 100 rpm and will not start in cold weather.



(a) (b)

Figure 7. ***(a)*** *Starter torque is close to the engine friction at low rpm* ***(b)*** *Resulting engine speed curvature*

IV. CONCLUSIONS

Choosing a ready-made starter for a diesel engine under design is an important decision. The starter performance curves given according to the ISO 8856 standard are not suitable for direct comparison with the engine friction curve. With the proposed method in this study, the starter performance curves are made comparable to the friction force-rpm curves of the engine. By using the Simulink program, it can be simulated to which rpm the selected starter can rotate the engine. In this way, it can be easily concluded whether the selected starter is suitable for the engine whose design is in progress. The proposed method has been tested with the model developed on Simulink for different scenarios, including stall, low rpm stuck and cold cranking risks and it has been shown to be usable for design decision.

The study also reveals the need for engine friction simulation or test results prior to starter selection. Although real measurement results are used for the starter, the accuracy of the developed method depends on the accuracy of the engine simulation data, since simulation results are used for the engine friction curve. It is planned to compare the developed method with test measurement results in future studies.

V. REFERENCES

[1] Delprete C, Razavykia A. “Piston ring–liner lubrication and tribological performance evaluation: A review”. *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology,* 2018.

[2] Hopfner, W., Lösch, S., Satschen, S., Winklhofer, E. “Friction test procedures in engine Development”. *Proceedings of the Conference: 5. Tribologie und Effizienztagung*, Györ, Hungary, 2018.

[3] Lee, S., Kang, J. & Park, S. “Measurement and modeling of crank train friction in light-duty diesel engines”. *J Mech Sci Technol,* vol. 34, pp. 889–903, 2020

[3] Allmaier, H., Knauder, C., Sanders, D. et al. “Combination of Measurement and Simulation to Analyse Engine Friction”. *MTZ Worldw,* vol. 77, pp. 66–71, 2016

[4] Johansson, Emma M. V. and Sofia Wagnborg. “Analysis of Engine Cold Start Simulation in GT-Power.” M.S. thesis, Department of Applied Mechanics Division of Combustion, Chalmers University of Technology, Göteborg, Sweden, 2014.

[5] Iskra Avtoelektrika. (2022, November 25). *Starter Motors*. [Online]. Available: http://www.iskra-agv.cz/us/pdf/starter_motors.pdf(URL)

[6] Patil, Atul B., and Nitin S. Ranade. “Computer Simulation of an I.C. Engine During Cranking by a Starter Motor.” *SAE Transactions* vol. 102: 911–17. 1993

[7] Vsarath Chandran. (2015, October 16) *Starter motor selection and vehicle system considerations.* [Online]. Available:https://autoelectricalsystems.wordpress.com/2015/10/19/starter-motor-selection-and-vehicle-system-considerations/

[8] Azzouaz, George. “Modeling And Simulation Of An Automotive Diesel Engine Cranking System” M.S. thesis, Department of Energy and Environment, Chalmers University of Technology, Göteborg, Sweden, 2005.

[9]. Mellblom, F. ‘Start modelling for heavy trucks’, Ph.D. dissertation, Department of Electrical Engineering, Linköping University, Linköping, Sweden, 2004.

[10] Knauder, Christoph & Allmaier, Hannes & Sander, David & Sams, Theodor. “Investigations of the Friction Losses of Different Engine Concepts, Part 1: A Combined Approach for Applying Subassembly-Resolved Friction Loss Analysis on a Modern Passenger-Car Diesel Engine” *Lubricants*, vol. 7, no. 5, p. 39, Apr. 2019.