Determination analysis of main dimensions of induction motors for railway propulsion system

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ABSTRACT

Induction motors are used in industrial production processes. As for its use as a traction motor, it requires special design and manufacture. The type of induction motor that is widely chosen as a traction motor for railways is a squirrel-cage three-phase induction motor. The main consideration for the selection or design of an induction motor as a railway traction motor is the torque requirement to drive the train. Other parameters that are considered in the selection of an induction motor as a traction motor include available spaces for installation. This research is using a three-phase, 2,300 VAC, 480 kW, and 50 Hz induction motor. By using the application program for determining the parameters of the induction motor, it shows that the motor produces a moderate output coefficient (between maximum and minimum) and produces a torque greater than induction motor torque in general. As a result of the analysis, this induction motor is suitable to be used as a motor for the railway, where greater torque is required.

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1. INTRODUCTION

Three-phase induction motors are used in many industrial production processes, such as pumps, blowers, compressors, conveyors, and others because of their simple construction, easy operation, low maintenance and operating costs, and ability to be connected directly to the power grid [1]-[3]. As for its use as a traction motor, it requires a design and manufacture that meet the application requirements, including for high-speed railway with a torque vs. speed curve that is suitable for driving the vehicle. To achieve the required speeds, the torque-speed control system of the induction motor and the inverter must be carefully considered [4]-[6]. This requirement is different for each use of the same motor in other industrial applications [7], [8]. The type of induction motor that is widely chosen as a traction motor for high-speed railways is a squirrel cage three-phase induction motor because its performance suits electric vehicle (EV) propulsion applications [9], [10]. These performances include high efficiency as well as great power and torque factors [11]-[13].

One of the steps in the process of designing an induction motor is determining parameters [8], [14]. Determining parameters in induction motors is one of the efforts to achieve high-performance induction motor drives because the performance of induction motors depends on the parametric characteristics of the motor and its accurate results [15], [16]. This is because one of the important aspects of traction motor design is the electromagnetic and thermal design, which is influenced by, among other things, motor size, stator-rotor configuration, and cooling method [17]-[19].

Based on all of the above, an analysis of the process of determining the main parameters, especially the diameter size of a three-phase induction motor that will be used as a traction motor is described. The process of determining these parameters uses software, which is of course built based on the theoretical design process [20]-[22]. In general, the analysis of induction motor parameters is about the specifications listed on the name plate. While the analysis presented in this paper is the output coefficient parameter which provides an overview of the diameter listed on the name plate. Referring to all of the above, an analysis of the main dimensions of induction motors designed and manufactured to be used as traction motors on high-speed railways is carried out, therefore the aim of this paper is to evaluate the design results of the main dimensions of induction motors for railway propulsion system that will be placed in very limited space based on the value of their output coefficient.

2. METHOD

It begins with studying the initial design of the Jakarta-Surabaya high-speed railways prototype, which is continued by studying the design and fabrication of the traction motor prototype. The traction motor has a larger volume size compared to the volume size of a regular railways traction motor. One technique for analyzing an induction motor from the perspective of its volume is to analyze the status of its output coefficient. The analysis of the output coefficient is continued by analyzing its performance as an electric railways traction motor.

2.1. Requirements for drive motors and their placement

The main consideration for the selection or design of an induction motor as a railway traction motor is the torque requirement to drive the train. In addition, other parameters in the selection or design of an induction motor as a traction motor driving a railway include the electrical parts that consist of the working voltage (voltage rating), input frequency, current, and motor capacity. Meanwhile, the mechanical parts are, among others, stator diameter, rotor diameter, and shaft diameter. Another consideration is that the traction motors used as traction motors on electric trains to produce propulsion are usually installed directly on the train wheel axle. Thus, the traction motor is designed according to the space available for installation and the train operation plan, as shown in Figure 1. In Figure 1, a Boogie with an H frame is equipped with two traction motors. The boogie is mounted on a train equipped with a traction motor. The train that will be driven is a series of four trains, as shown in Figure 2.

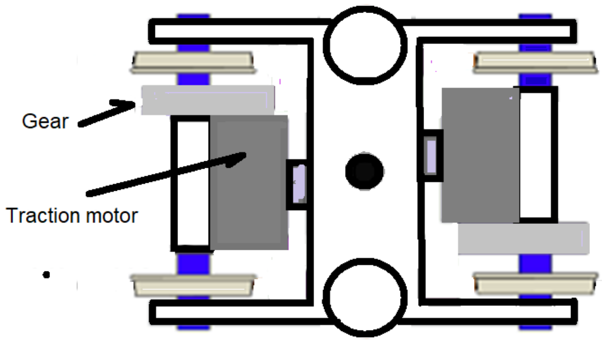

Figure 1. Traction motor installation on the train Boogie

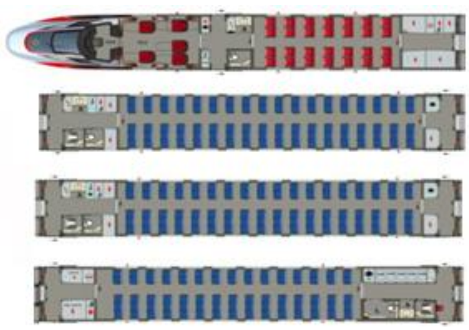

Figure 2. Series consisting of 4 trains

Figure 2 shows a set of high-speed railways that has been designed, consists of four trains: a train equipped with steering (speed) control, a train equipped with traction motors to move the railways, a trailer train, and another train equipped with traction motors. The general method and procedure for operating a high speed railways are explained in Figures 3 and 4. Figures 3 and 4 explain the torque and power required in the process of operating a railway, namely the characteristics of the relationship between the torque required and the speed at which the railways operates [23]-[26]. From a stop condition, the train is driven by providing constant maximum torque until it reaches the base speed, as seen in Figure 3. This is done by providing a linearly-increase power until it reaches the maximum required power, as seen in Figure 4. Furthermore, the given power is maintained constantly until it reaches maximum speed. As a result, the torque working on the train decreases parabolic until it reaches its maximum speed.

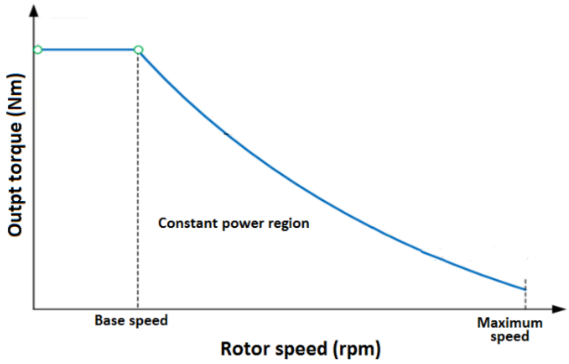

Figure 3. Characteristic of torque vs speed at trains operation

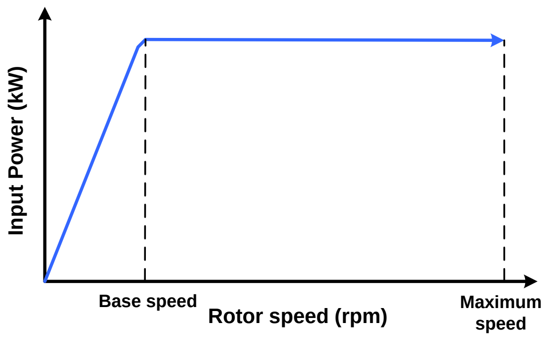

Figure 4. Characteristic of power vs speed at trains operation

2.2. Specification design of traction motor

Based on the explanation above, a three-phase induction motor was designed and manufactured as a model and prototype of three phase induction motor as traction motor for high-speed trains with a torque-speed curve suitable for vehicle propulsion applications as shown in Figure 5. The technical specifications of the induction motor that has been designed and manufactured, as shown in Figure 5, which will be used as a prototype traction motor for high-speed railways [27], are as shown in Table 1.

Figure 5. The three phase induction motor that has been designed and manufacturer

Table 1. Specification of traction motor railway design

Parameter	Value
Motor type	Squirrel cage induction motor
Phase	3-phase
Capacity	480 kW
Voltage	2,300 Vac
Frequency	50 Hz
Torque	1,800 Nm
Rotational speed	2,500 rpm

2.3. Main dimension traction motor

Basically, the induction motor as a traction motor in accordance with its function of converting electrical energy into mechanical energy, consists of two major parts, namely the stator and the rotor. There is an air gap between the two parts. The main dimensions of the traction motor are the stator diameter (D) and stator length (L) as shown in Figures 6 and 7.

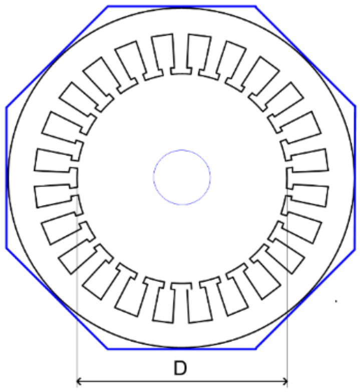

Figure 6. Diameter of stator (D)

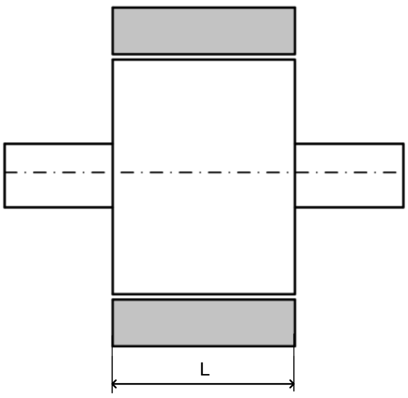

Figure 7. Length of stator (L)

The stator is part of the induction motor which produces a magnetic field that is induced into the rotor through the air gap [28], [29]. If the stator winding is connected to a three-phase electrical energy source, three-phase current flows in the three stator windings with a phase angle difference of 120°. The amount of input power is shown in (1).

$$VA = \frac{HP\ x\ 0.746}{\eta\ x\ cos\ \theta} \tag{1}$$

In which, η is efficiency and cos θ is power factor.

Based on the capacity of the motor to be designed, the main dimensions of the motor stator can be calculated, namely its diameter and length, using the formula given in (2).

$$D^2L = \frac{KVA}{Cn_s} \tag{2}$$

In which: $C = 17.4\, B_{av}\, ac\ x\ 10^{-5}$, x cos φ
D=diameter (hole) of stator
L=length core of stator
n_s=sync speed in rps

From (2), there are 2 factors that influence the determination of the main size of the stator, namely output coefficient (*C*) and speed (n_s). A high *C* or n_s value results in a small D^2L value. Since *D* is the stator diameter and *L* is the stator length, a small D^2L value indicates a small electric motor volume. Flexibility in the length and diameter of the stator shows that the length of the stator is inversely proportional to the square of its diameter; thus, an interesting correlation arose when determining the dimensions of the two. The correlation is that when the diameter is increased, the length is reduced, and vice versa. The value of the synchronous speed (n_s) is given in (3).

$$n_s = \frac{120f}{P} \tag{3}$$

In which: f=frequency in Hz
P=number of pole
n_s=sync speed in rps

Furthermore, the discussion/analysis in this paper will focus on the influence/effect of the output coefficient (*C*) value on the planning/design of induction motors that will be used as railway traction motors. A small *C* value produces a large motor volume and a large *C* value produces a small motor volume [30].

3. RESULTS AND DISCUSSION

Designing an induction motor as a traction motor for a railways is the first step in producing a good motor to run the train properly and efficiently. The design process for determining the size of the machine is one of the most important primary steps that has resulted in a motor with a volume that fits the available space, and a torque that can move the railways according to the design. One of the important parameters in the design process of a three-phase induction motor is its efficiency. In general, the efficiency of a three-phase induction motor is between 85% and 96% with a power factor between 0.8 and 0.85 [31], [32].

To analyze the design and fabrication results of a three-phase induction motor using its output coefficient (*C*), the minimum *C* value and the maximum *C* value are first calculated. The parameters needed to calculate the output coefficient are magnetic loading (B_{av}) and specific electric loading (ac). The values of the two parameters are magnetic loading (B_{av}) between 0.3 and 0.6. While the specific electric loading (ac) value for induction motors with a capacity greater than 100 kW is between 30000 and 45000 [31]. Based on these things, the magnitude of the parameters used to calculate the minimum *C* value and the maximum *C* value according to (2) is as seen in Table 2. Based on the parameter values of the three-phase induction motor in Table 2, then by using (2) the minimum output coefficient value is 1.13 Tesla, and the maximum output coefficient value is 3.8 Tesla.

Table 2. Three phase induction motor parameter values

Parameter	Minimum value	Maximum value
B_{av}	0.3	0.6
ac	30,000	45,000
$cos\ \theta$	0.85	0.9
η	0.85	0.96

As previously explained, the traction motor is installed on a bogie with limited space. However, this can be done with flexibility in the length and diameter of the stator as seen in (2), which shows that the length of the stator is inversely proportional to the square of its diameter; thus, an interesting trajectory arose when determining the dimensions of the two. The trajectory is that when the diameter is increased, the length is reduced, and vice versa.

By using software for induction motor design, the stator diameter is set at 0.478 m and the stator length at 0.295 m. Based on this value, the D^2L price in (2) is 0.067 m^3. Meanwhile, the value of ns (synchronous speed) based on (3) is 2700 rps. Based on the ns value, (2) resulted in a *C* (output coefficient) of 2.65 Tesla. This value ranges between 1.3 Tesla as the minimum value and 3.8 Tesla as the maximum value. Where a small *C* value produces a large motor volume and a large *C* value produces a small motor volume [30].

The moderate output coefficient value indicates the moderate value of the design result of the main dimensions of the induction motor as a traction motor, namely its diameter and length, based on its output coefficient value. However, additional and in-depth research may be needed to further confirm how to more effectively determine the value of two opposing parameters such as the diameter and length of the induction motor as a railway traction motor. The acceptance level of the design results of three-phase induction motors for high-speed railway traction motors has been comprehensively analyzed, namely the length and diameter. However, additional and in-depth studies may be needed to confirm the quality of its operation, especially regarding its use as a traction motor for high-speed railways as shown in Figures 3 and 4. In addition, future research that is no less important in the design and fabrication activities of induction motors as traction motors is research on changes in the output coefficient value at various speeds. This is needed because in its operation the railways experience several changes in speed, including when traveling along a path that has an elevation angle, when traveling along a circular path with a certain radius.

4. CONCLUSION

The process of determining the main dimensions of an induction motor as a traction motor has been described and analyzed, namely dimensions of stator. To optimize the design results of a three-phase induction motor as a railway traction motor, an analysis of its output coefficient (C) is required. The three-phase induction motor has been designed and fabricated as a motor for the high-speed railway with a capacity of 480 kW. This induction motor has a *C* of 2.65 Tesla. This value ranges between 1.3 Tesla as the minimum value and 3.8 Tesla as the maximum value. The parameters used for maximum and minimum values are magnetic loading (B_{av}), specific electric loading (ac), motor efficiency (η), and power factor ($cos\ \theta$).

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AUTHOR CONTRIBUTIONS STATEMENT

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Eko Syamsuddin Hasrito	✓	✓	✓	✓	✓			✓		✓		✓		✓
Sofwan Hidayat				✓	✓	✓				✓		✓	✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author, [SK]. The data, which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

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