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# Prototype Development for Predicting Eccentricity Based on Rotating Unbalanced Behavior of Train

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**Abstract.** This paper presents a prediction of the centrifugal force caused by the dynamic unbalanced of train wheelset on a developed scale down test bench. The wheelset dynamic unbalanced can be one of reasons for the derailment accidents on trains. Dynamic unbalance represented by the produced centrifugal force can be the main factor causing wear on bearings, noise, vibrations on the train, and the fatal cause of trains accident. The behavior prediction is carried out by applying various eccentricity values by varying the additional weights. The centrifugal force prediction of the developed equipment then compared with the actual size wheelset's unbalance behavior. The comparison shows a similar pattern between this miniature and the actual size test-bench in terms of the magnitude of the centrifugal force at various eccentricities and rotational speeds.

**Keywords:** train, wheelset, railway, rotating unbalance

## 1 Introduction

Wheelset is an important component of a train including the travel safety and comfortability [1]–[3]. The main reason can be several factors, such as microstructural differences in materials, asymmetry of the wheels, inaccurate wheel profiles caused by asymmetrical wear (wheels out of roundness), wheel assembly errors, the main inertia axis passing through the wheelset's center of gravity which is not parallel to the wheelset axis of rotation [4]. One of the examples is an imbalance of centrifugal force that occur when the wheel rotates, because of an imbalance in the wheel mass. Centrifugal force is one of the important factors causing bearing wear, train noise and vibration, and the most fatal can cause the train to derail [4], [5].

In recent years, along with the development of technology in the field of sustainable transportation, increasing the speed of train operation has become an important means to increase competitiveness between trains. Thus, the frequency of periodic excitation forces will increase that greatly affect the balance, train quality, train performance when turning, or even reduce the life of the wheelset, bearings, and other components of the train. Unbalanced wheels are a source of periodic excitation forces, and the effect of wheel balance on travel quality becomes very important due to the increasing speed of trains. In order to improve driving safety and driving comfort, the dynamic imbalance value should be strictly limited especially for high-speed trains [6]–[9]. The periodic motion in the axial change of the wheelset on a straight rail is known as hunting oscillation. This movement arises from the frictional force that accelerates the wheelset in the direction of its displacement, as well as the contact force between the wheels and the rails in opposite directions so that the wheelset returns to the center of the rail [10].

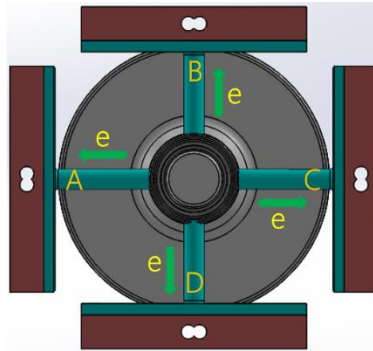
Wheel balance and dynamic unbalance values in wheelsets have become a concern in many countries, which have been controlled to a certain range according to several standards. For passenger train components, it is regulated in the UIC (International Union of Railways) and Japanese standards that the wheelset unbalance limit value must be based on the maximum acceleration of the bogie. The allowable unbalance value of the wheelset can be determined when the maximum acceleration of the wheelbase to the center of the train is  $1 \text{ m/s}^2$ . According to UIC standards, the maximum unbalance value on the wheelset must be less than 50 gr when the train is traveling at a speed of more than 200 km/h. Based on these problems, this it is necessary to have a test tool to examine the wheelset imbalance on the train. This tool will be used to determine the behavior of train wheels in various imbalance scenarios. Therefore, this paper aims to develop a prototype capable to predict eccentricity. The paper is divided into two parts, the methodology and the results with discussion. The methodology consist of the simulation scenarios when the unbalanced phenomena occur and the possible modification of the parameters.

## 2 Method

The test rig is designed based on a D-D unit wheelset based on AAR wheel arrangement. This type of wheelset has been used in train to ship materials from one place to another place, such as coal. The developed prototype is a scale down test rig. Hence, to calculate the centrifugal force on the prototype wheelset design it can also be applied to the original wheelset design, it is necessary to do a scale comparison between the two wheelsets. The scale comparison between the original wheelset and the prototype wheelset is 10:1.

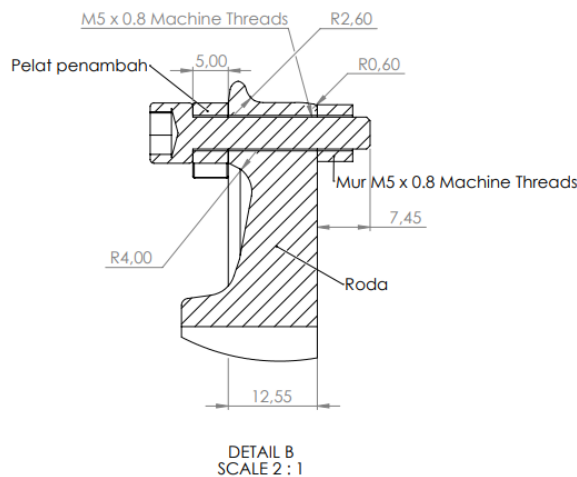
Based on the AAR (Association of American Railroads) standard with the document title "Manual of Standards and Recommended Practices" the original shaft axle uses carbon steel material with heat treatment and for the wheels also uses carbon steel. Both have a density of  $7850 \text{ kg/m}^3$ . Meanwhile, to determine the material for the shaft and wheels of the prototype by equating them to the original components because they will be scaled up later.

The design concept of this tool will be carried out by rapid prototyping in the next progress and used to test the wheel eccentricity that occurs due to the misalignment of the main inertia axis with the wheel rotation axis. The tool is driven by a driving motor at a constant speed. There are at least 3 levels of maximum rotational speed and each with its variations based on the TQI (Track Quality Index) quality value used, namely the maximum speed if the TQI quality is poor, moderate, and good. To determine the magnitude of the centrifugal force that occurs on the wheel, the design concept of the tool design is equipped with 4 sensors which are illustrated by the letters A, B, C and D in the image below.



**Figure 1.** Sensor placement in the test rig

The magnitude of the axis shift is called the eccentricity which is denoted by the letter "e" in mm. In calculating the imbalance of the wheelset design concept, a non-centric wheelset is carried out. One way to create an unbalanced condition can be by adding weight or reducing the weight on the wheels, so that the wheel mass will be different, and the wheelset will experience a dynamic imbalance condition. The illustration of adding and subtracting weight on the wheels is as follows.



**Figure 2.** Additional weight mechanism

The method of increasing the load used is by perforating the side of the wheel, then installing the load increase plate and then locking it using nuts as shown in Figure 2. To vary the output of the centrifugal force, it is necessary to make several plate designs with different thicknesses. Variations in plate thickness dimensions represent the additional weights with 0.63, 0.18, 1.08, 2.16, 3.24, and 4.32 g.

The addition of a load with a certain variation on the wheel under test results in a measured centrifugal force on the sensor installed on the tool. This is because the main axis of inertia passing through the center of gravity does not coincide with the axis of rotation of the wheel. So that when the wheel rotates at a certain speed, the centrifugal force (F) eccentricity of the wheel can be expressed as in Eq. (1) [4], [11], where, F is Force (N), M is wheel mass (kg), n is wheel rotational speed (rpm), and e is Eccentricity (mm).

$$F = Me (\pi n/30)^2 \quad (1)$$

In railways, the term Track Quality Index (TQI) is known. The Track Quality Index is a standard value of the railroad track used to evaluate the quality of the railroad track. The value of the TQI can monitor track degradation and maintenance operations, can summarize and display track sections, and correlate with track safety and ride quality scores. The Track Quality Index is grouped into 4 categories, namely very good, good, moderate and bad. The standard values used by railway companies in Indonesia are as follows.

TQI < 35	: v > 80 km/hour	good
35 < TQI ≤ 50	: 35 < v ≤ 50 km/hour	moderate
TQI > 50	: v < 60 km/hour	poor

The grouping of TQI values can be used to determine the allowed linear speed on a certain path. After knowing the value of the linear velocity used, it needs to be calculated and converted into angular velocity with the following formula:

$$n = \left( \frac{60}{2 \pi r} \right) v \quad (2)$$

Where,  $n$  is angular velocity (rpm),  $r$  is wheel radius (m), and  $v$  train velocity (m/s).

### 3 Result and Discussion

The use of rotational speed is based on real scale of train at the available data in a published report in the literature [12]. The rotational speed that will be used in calculating the centrifugal force on both the scaled down and scaled up wheelset uses a moderate quality of TQI. Calculation of centrifugal force uses rotational speed calculation based on the original wheelset for validation when measuring the prototype wheelset.

Mass imbalances that occur in the wheelset are divided into two, namely specific imbalances with an ideal distance (the position of mass and mass imbalance is known) and mass imbalances with known mass and mass imbalance positions.

The calculation of wheelset centrifugal force with this eccentricity variation is carried out in two calculation variation scenarios. That is with variations in distance ( $r$ ) and variations in the mass of the increase in load ( $m$ ). In this scenario of variation of the load increase, plates with different thicknesses are used so that it can be used to calculate the eccentricity caused when the mass of the increase in load varies. With an additional load of 5.13 g, the eccentricity is shown in Table 1 and Table 2 for full scaled and a scaled down wheelset, respectively.

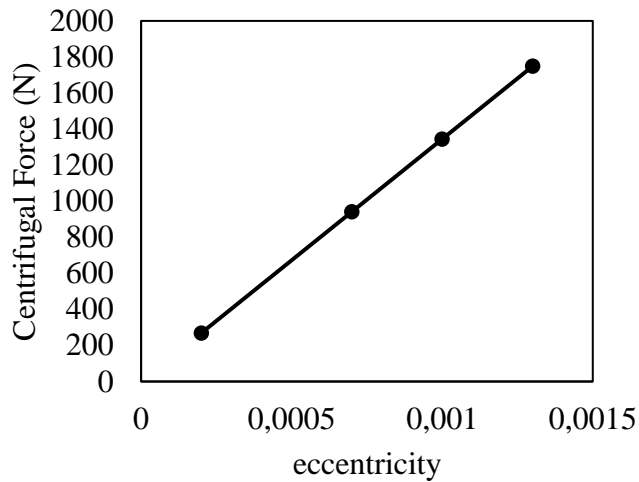
Table 1. The eccentricity in a full scale wheelset with assumed additional weight

No	m (g)	M (kg)	$\bar{r}$ (mm)	e (μm)	e (mm)
1	5,13	2,06	25	62,2573	0,0622
2	5,13	1544,7	250	0,83026	0,0008

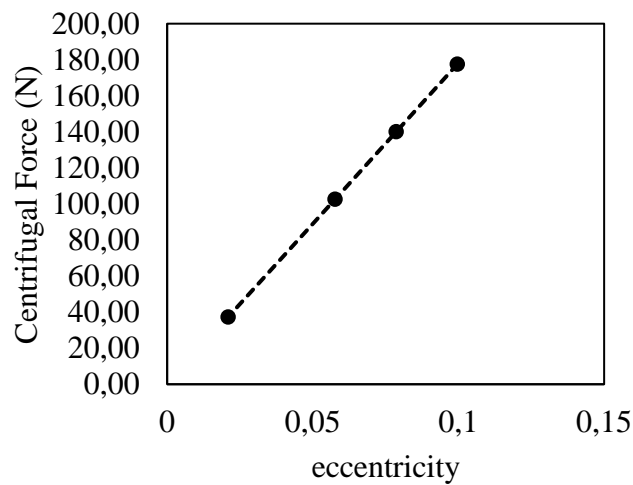
Table 2. The eccentricity in a scaled down wheelset with assumed additional weight

No	m (g)	M (kg)	$\bar{r}$ (mm)	e (μm)	e (mm)
1	5,13	2,06	40	99,6117	0,0996
2	5,13	1554,7	400	1,31987	0,0013

Based on Table 1 and 2, it can be concluded that the magnitude of the mass imbalance in both prototype and original wheelset types is 0.0622 mm and 0.0008 mm, respectively, at the distance between the load adder and the center axis of rotation ( $r$ ) of 25 mm and 250 mm. While the distance between the load increaser and the center axis of rotation ( $r$ ) of 40 mm and 400 mm is 0.0996 mm and 0.0013 mm, respectively. The unit of  $e$  is converted to mm from  $m$  because in the next calculation step  $e$  requires units of mm. Then, the centrifugal force with variations in eccentricity is obtained in the scenario of variations in the distance between the load increaser and the center axis of rotation as shown in Table 1 and Table 2 for full scaled and a scaled down wheelset, respectively. Besides the distance between the additional weight and axis, the additional weight values can also affect the centrifugal force as shown in Figure 3 and Figure 4 for full scale and scaled down wheelset, respectively. Based on both figures, the rotational speed of the wheelset affects the centrifugal force generated. The higher the rotational speed of the wheelset, the greater the centrifugal force generated. From the calculation of the centrifugal force between the original wheelset and the prototype, it can be concluded that the mass of the wheelset is also a factor that affects the magnitude of the centrifugal force generated.



**Figure 3.** Centrifugal force prediction at various additional weight for full scale wheelset



**Figure 4.** Centrifugal force prediction at various additional weight for scaled down wheelset

#### 4 Conclusion

The dynamic unbalance test rig prototype consists of three main components, namely Wheelset components, frame components, and drive components. The wheelset component consists of a prototype axle axle, a prototype train wheel, and a ball bearing. The components of the tool frame consist of the base, base, and wheelset support. The drive component consists of the drive motor, clutch, and clutch shaft. The value of dynamic imbalance is influenced by several factors, one of which is the addition of a load on the train wheel circuit. The greater the additional load on the wheel circuit, the greater the imbalance that occurs in the wheel circuit. The device will be developed further in the future by fabricating and simulating with more parameter variations.

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