Preliminary Analysis in the Improvement Turning Abilities in Design of the Monorail Bogie PT. MBW Indonesia

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**Abstract:** A straddle type monorail is the most widely used as means urban transportation system. It can be implemented in order to solve the problem of urban transportation and to support the concept of a light transit urban mobility of sustainable transport system. In the last five years, PT. MBW has started a study the design and manufacturing of straddle type monorail in Indonesia. In this research, we intend to propose the new design concept of the bogie more specific than the design standard available because the urban city topography in Indonesia has not developed yet to provide an area specific for installation a monorail facility. One of the design parameters that will be improved is the turning-ability and gradient-ability. The normal standard turning ability of a monorail for some products in the world has a minimum radius of 40-60 m, while the gradient-ability is about 5-6 %. The preliminary analysis in this research is to improve the turning abilities of monorail bogie and the effect of monorail motion stability. Bogie design will be accomplished by using the method of virtual prototyping.

**Introduction**

The monorail is one of a green transportation system that running on a single guide track mechanism. The first vehicle running on single track has been patented in UK by Henry Robinson Palmer on 22 November 1821\textsuperscript{[1]}. Generally, monorail design divided in two models which is suspended type and straddle type. The straddle type is the most widely used for the urban transport system because of the capability to adopt the various length sizes according to the design requirement. This solution has a good deal with the concept of a light mass transit for urban mobility of the sustainable transportation system.

Ishikawa (1999)\textsuperscript{[2]} predicted that straddle type of monorail will lead in the future of the mass-transit system. Kubawara (2001)\textsuperscript{[3]} proposed small type of the straddle monorail in the medium range of urban transport system, because of benefits in terms of environmental improvements, construction time, and reducing the investment. Besides that, Siu (2007)\textsuperscript{[4]} has made analysis of the light transit system innovations for urban mobility in the perspective to develop sustainable transport systems.

In terms of the footprint's wheel shape, the straddle type can be divided into three groups: Alweg, Steel Box Beam, and Inverted T. Alweg is the name of the manufacturer that developed the first monorail using simple model of footprints (Fig. 1a). Actually the Alweg types are widely adopted by world manufacturers such as Bombardier, Hitachi, and Scomi. The steel box beam type is used for small size of monorail running on steel guide-way structure and generally to serve in short distance of urban transportation or tourism area (Fig. 1b). The type of inverted T is used on the specific guide-way having the shape of cross-sectional resembles an upside-down of letter T. This model has been developed by the Urbanaut manufacturing (Fig. 1c).
Bogie of Straddle Monorail

A monorail's body is supported by a bogie which has traction and stabilizing steering wheels system. Conventionally, two bogies are mounted on each body of monorail. However, there are also a model which has a bogie situated on the connection between the two bodies (articulated bogie). Commonly, a monorail driving traction use an electric motor which mounted on each traction wheel.

Monorail with articulated bogie has smaller turning radius than the independent model (conventional bogie). There are two types of bogie wheel axle design which is single and double axle. Although the single axle has a turning radius more smaller and lighter than the double axle, but the ability to support the burden is relatively lower. Currently, most of the straddle type of monorail uses double axle bogies, to support the mobility with high load and stability in motion.

Bogie with double axle has the turning ability divided into two arrangements which is conventional fixed-axle bogies and steerable-axle bogies. In general, steerable axle bogie have better motion stability than fixed types.

Fig. 3: Bogie axles type: (a) fixed axle bogie and (b) teerable axle bogie

The bogie mobilization at the circular curve of a trajectory can be improved by making the shaft's axes in line with radius of curve trajectory R (steerable axle bogie) (Fig. 4a). Another way...
is to increase a free area, $e$ of against radius trajectory (fixed axle bogie) (Fig. 4b). Free area, $e$ against the line trajectory, can define as:

$$e = R - R \cos \theta = R(1 - \cos \theta)$$

(1)

While the distance between the steering wheel shafts (guide wheelbase) is about;

$$L = 2R \sin \theta$$

(2)

from the Eq. 1 and 2 will be obtained the relationship equation;

$$R = \frac{e}{1 - \cos \theta} = \frac{L}{2 \sin \theta}$$

(3)

With a using the relation $\sin^2 \theta + \cos^2 \theta = 1$, and using Eq. 3 will be obtained the equation;

$$\left(\frac{L}{2R}\right)^2 + \left(1 - \frac{e}{R}\right)^2 = 1$$

(4)

Using Eq. 4, we obtained the relationship between the radius of curvature, $(R)$ the length of guide wheel base, $(L)$ and free areas against the track curvature, $(e)$ which can be defined by the Eq. 5. This equation related to the geometry trajectory curvature of the bogie;

$$R = \frac{L - 4e^2}{8e}$$

(5)

**New Monorail Design of PT. MBW**

The first Indonesian monorail prototype designed by PT. MBW has adopted a model of Alweg footprint and used two fixed axles bogie mounted independently (conventional arrangement). The monorail has a payload capacity for 125 passengers per carriage and a maximum train series of six cars. The turn ability of the fixed axle bogie model can be increased with enlarge the free area, $e$. A dimension of a free area, $e$ limited by geometry the length of guide wheelbase and width of the bogie. A new model prototype is being made to improve the mobilization on the curvature trajectory with the make the position of the stabilizing wheel axle in line with the axle steering wheel. Virtual and numerical simulation analysis have been done using Solidworks Motion Study software.
The first monorail prototype has a total weight of 24,000 kgm and the bogie weight is about 1.500 kgm. The motion rate of monorail was designed for maximum speed of 70 km/h on straight trajectory and 20 km/h on the curvature. The vertical curvature is still in standard range and limited to minimum radius of 1000 m. The running ability at minimum radius horizontal is about 60 m and the maximum gradient ability is about 5%. Using simulation model, we evaluated the mobilize ability, due to the change of position of stabilizing wheel position, from position in between with the steering wheel to the parallel position with the steering wheel.

**Results and Discussion**

The bogie mobilization was simulated and analysed in two conditions of the different placement of stabilizing wheels; in between (Fig. 5a) and in line to the axle steering wheel (Fig. 5b). The simulation was conducted only at motion rate analysis of the bogie on the longitudinal axis, so the contact analysis that occurs in stabilizing wheel and the steering wheel was not included. In the simulations, we introduced a velocity at the straight-line trajectory is 70 km/h (19.46 m/s), and at the curvature trajectory is 20 km/h (5.56 m/s). The load received for each bogie was 10.5 tons of the total weight of monorail with passenger 24 ton/car, while the weight of each bogie is assumed to be 1.5 tons. The contact resistant between wheels and the track guide-way was modeled using rubber and steel at dry conditions. Simulation results are shown in Fig. 6 and Fig. 7.

![Fig. 5: New model of wheel stabilizer modification](image)

(a) stabilizing wheel in between steering wheel  (b) stabilizing wheel parallel with steering wheel

![Linier Velocity at longitudinal Axis](image)

Fig. 6: Gradual velocity of the bogie at constant velocity of 19.46 m/s on straight pathway

Fig 6(a) show gradual velocity of the bogie with stabilizing wheel position located in between the steering wheel. During running on the straight trajectory, it has a better mobilization compared...
the bogie with stabilizing wheel located parallel to the steering wheel. In general it is caused of increasing the number of stabilizing wheel so that it increase the contact friction and sensitivity. This friction is a barrier for movement mobilization. The mobilization motion of bogies while running on the curvature trajectory are simulated as follows:

![Graph A](image1.png)  
**Fig. 7:** Gradual velocity at constant velocity of 5.56 m/s on radius curvature of 60 m

(a) stabilizing wheel in between steering wheel  
(b) stabilizing wheel parallel with steering wheel

Fig. 7 show that bogie with position of stabilizing wheel mounted parallel to the steering wheel has a better mobilization effect.

**Conclusion**

The bogie with a wheel stabilizer mounted in between the steering wheel, has less friction at straight way but has less mobilization when running at most trajectory curvature compared with one which mounted on parallel position. The design of a new model steerable axle bogie has a good mobilization in most of trajectory conditions.

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