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STUDY ON THE ROAD TRANSMITTED VIBRATION OF A MOUNTAIN BICYCLE

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Graphical abstract

Abstract

Mountain bicycle (MTB) is one the most favorite vehicles in the globe. MTB comfort, in consequence, has then become a challenge issue to the manufacturers since MTB nowadays is not only being used for sports and exercises, but also for daily activities. One of the simplest methods to assess vehicle comfort is by evaluating their vibration level. Thus, this paper presents an experimental assessment on the road transmitted vibration on a MTB through a field test subjected to different road surface conditions and tire sizes. The result shows that the cycling comfort is significantly affected by the road roughness condition and tire size. As the road is rougher, higher force excitation is generated to the bike which is then generating higher vibration. Similarly, as the contact area between the tire and the road is increased, bike vibration is also significantly increased.

Keywords: Vibration; road transmitted vibration, mountain bicycle

Abstrak

Basikal gunung (MTB) adalah salah satu kenderaan yang paling kegemaran di dunia. Keselesaan MTB, akibat, kemudiannya telah menjadi satu isu cabaran kepada pengeluar sejak MTB pada masa kini bukan sahaja digunakan untuk sukan dan latihan, tetapi juga untuk aktiviti harian. Salah satu kaedah yang paling mudah untuk menilai keselesaan kenderaan adalah dengan menilai tahap getaran mereka. Oleh itu, kertas kerja ini membentangkan penilaian eksperimen di getaran dihantar pada MTB melalui ujian lapangan tertakluk kepada keadaan permukaan jalan yang berbeza dan saiz tayar. Hasil kajian menunjukkan bahawa keselesaan berbasikal yang ketara dipengaruhi oleh keadaan kekasaran jalan dan saiz tayar. Sebagai jalan yang kasar, pengujaan kuasa yang lebih tinggi yang dihasilkan untuk motosikal yang kemudian menghasilkan getaran yang lebih tinggi. Begitu juga, sebagai kawasan sentuhan antara tayar dan jalan raya meningkat, getaran basikal juga meningkat dengan ketara

Kata kunci: Getaran; getaran dihantar; basikal gunung.

1.0 INTRODUCTION

It has been known that over past decades, bicycle has been become one of the most favorite vehicles in the world. People love riding bicycle because it can increase their body health and increasing their cardiovascular ability. Besides that, increasing fuel price issue every year also makes people to think again when travelling in short distance using automobile or motorcycle. Since its presence in eighteen centuries, bicycle technology has been rapidly developed involving strength reliability, advanced materials and also the aerodynamic shape.

One of the most important aspects for the cyclist is comfort issue, which is commonly represented by the vibration of the bicycle. Many researchers have been conducting research on this particular topic. Champoux *et.al.* [1] investigate bicycle structural dynamics of a racing bike in particular the modal analysis of the frame with respect to comfort and durability. The study was conducted both in laboratory using Single Input Multiple Output (SIMO) and Multiple Input Multiple Output (MIMO) analysis as well as on a field tracking test. The result gives a useful primary finding which informs that the dynamic comfort is closely related to the quality of the road surface. However, on a newly paved road, there is no issue with the comfort at all. Wenhua *et.al*. [2] study the comfort level of an newly designed electric bicycle under different surface road condition using software simulation. The 5 d.o.f. dynamic model of the electric bicycle is made and successfully performing a good comfort level for all surface road condition as purposed. Petrone and Giubilato [3] develop a test method to evaluate the radial structural behavior of a racing bicycle wheel with respect to the rider's comfort. Three types of test namely static, cyclic and bump tests are conducted for four front wheels of different shape materials and spoke disposition. As an important result, the tire stiffness was apparently able to cover rim differences effects. Holzel *et.al*. [4] investigate the effect of surface road condition on a particular racing bicycle comfort. Four different surfaces i.e. new asphalt surface, new concrete slabs, cobblestones and self-binding gravel were tested. From rider's subjective perception, it is found that cobblestones gives high effective value which describes many and strong vibrations. It is followed by self-binding gravel in the second highest, concrete slabs then asphalt which has the lowest vibration. Vanwalleghem [5] studies the dynamic behavior of an instrumented bicycle corresponds to the cyclist's comfort. An integrated electronic piezoelectric accelerometer was fabricated and assembled on the bike to measure the velocity near the contact point i.e. handle bar and saddle. While for measuring force at those contact point is done by using strain gauges. The result shows that the method was very successful to measure comfort level of the riders and feasible enough to be used for further investigation related to the effect of tire pressure, cycling position, etc. Recently, Liu *et.al*. conduct a simulation study of a full suspension bicycle to analyze the pedaling force and comfort using dynamics analysis software ADAMS [6]. It is used to evaluate human body acceleration versus vibration frequencies. It is found that on a rough road, the suspension system may effectively reduce the human body vibration.

However, it seems only racing bicycle was of interest since most of the previous researches were only conducted using road or urban bicycle. There has been lack of investigation on the performance of mountain bicycle particularly in the comfort issue. According to the report by Corporate Research Associates Inc. for Parks Canada, mountain bicycle is very popular in many countries in the world especially the United States, Canada, Australia and New Zealand. It is also called as an ever expanding sport with numbers of types, segments or disciplines. Moreover, it already has an International Association with more than 32,000 individual members and 450 clubs [7].

This paper, therefore, presents a preliminary study on the effect of road transmitted vibration on a mountain bicycle in order to examine the comfort level. It is conducted experimentally both in the laboratory and practical field tracks. Parametric studies that have been done are involving speeds, tire sizes and road roughness.

2.0 EXPERIMENTAL

2.1 Bicycle Measurement Setup

Figure 1 shows the measurement setup for bicycle testing. Two accelerometers are placed on two different locations on the mountain bicycle i.e. at the seat post and front fork purposely to give additional information about overall frame damping performances. A mild steel platform of mounting for the accelerometer can be seen in Figure 2.

Figure 1 Bicycle measurement setup

Figure 2 Sensor placement: Seat post (left) and front fork (right).

These sensors are then connected to the VibPlot dynamic signal analyzer by m+p International through BNC cables to record and process the data. The logarithmic scale of the acceleration data in the unit of gravity *g* is post-processed and displayed in the computer.

2.2 Tires

Three different sizes of tire are investigated in this experiment which can be seen in Figure 3. While the tire technical specification is given in Table 1.

Figure 3 Tire sizes

Table 1 Tire specification

Brand	Maxxis Cross Mark	Michelin Wild Racer	Maxxis Larsen TT Exeption
Material	Natural Rubber	Natural Rubber	Natural Rubber
Width (in)	2.1	2.0	1.9
Diameter (in)	26	26	26

2.3 Road Surface

Figure 4 shows the simulated road surface conditions i.e. cement pavement, soil and gravel. Measurement for cement pavement was conducted indoor while for soil and gravel is conducted out door.

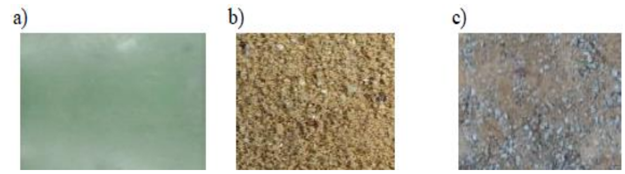

Figure. 4 Different road surfaces: a) cement, b) soil, c) gravel

2.4 Measurement Procedure

The measurement is conducted in three different cycling speeds i.e. 5, 6, 7 km/h for all tire size and road surface condition. The acceleration data is captured within 3 seconds on a 6 m track after steady speed achieved. This is to avoid noise reading and unwanted shocks which possibly happened in unsteady speed. The logarithmic value of acceleration is presented from 0 – 10,000 Hz frequency.

3.0 RESULTS AND DISCUSSION

3.1 Effect Of Speed

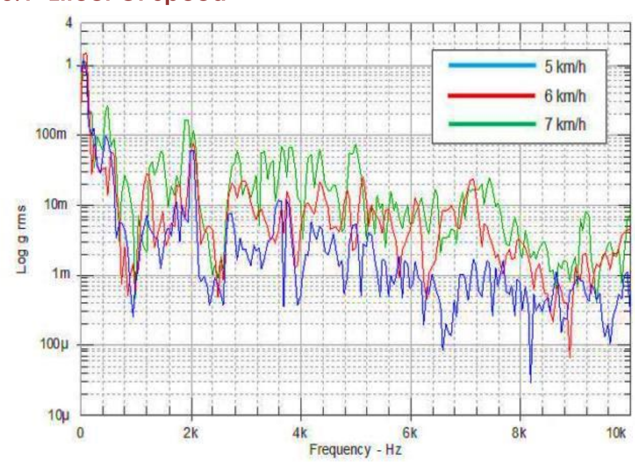

Figure 5 Effect of speed (2.0 inch tire, cement pavement)

Figure 5 shows the effect of speed on the bicycle vibration. The tire here is the 2.0 inch tire over cement pavement. It can be generally seen that the cycling speed is proportional to the bike vibration. The excitation force is obtained from the contact between the road and the tire of the bike. Since the rotational speed of the tire is assumed to be harmonics, the force excitation is therefore assumed to be harmonics as well. The graph shows that as the cycling speed increases, the excitation force considerably increases and gives higher vibration at the bike. This is very obvious since the excitation force is simply multiplied naturally with the increment of speed.

Meanwhile, higher bike vibration is also generated from the increment of pedalling force by the cyclist when the speed is increased, eventhough it is relatively much smaller compared to the road excitation force. Pedalling force comes from cyclist mechanical energy that is converted to the rotational force by the crankshaft which then transferring the energy to the tire. Obviously again, when the tire is running faster, the energy needs is required to be higher as well. Consequently, pedalling force should be higher which then giving higher vibration to the bike.

Moreover, as presented by Yan Bu, *et. al.* [9] the vibration properties of human body —whereas it is neglected here— also gives considerable influence to the bike. One should note that the human body vibration here is different with pedalling force. The human body vibration is more about response behaviour of human body to vibration since the human body reacts actively to vibration. It is more about response rather than excitation (i.e. human pedalling). Even so, this response apparently gives looping-like force to the excitation. In other words, when the cycling speed increases, human body response to vibration apparently gives additional force to the force excitation and finally increases the vibration of the bike. However, this human body reaction measurement requires another more sophisticated apparatus and involvement of psychological study, which needs larger subjects as well.

This is in contrast with motorized vehicle where initially the human body is considered as the biggest mass of the model and may possibly results as the most important aspects for the vehicle vibration [9]. However, the involvement of this human body reaction to vibration will be considered in the further study with some more detail models.

3.2 Effect Of Road Surface

Figure 6 shows the effect of road surface condition on the bicycle vibration. Smooth road apparently produces the lowest vibration and conversely, rough surface gives higher vibration. This confirms the results obtained by Holzel *et.al* [4] which shows similar pattern. Smooth surface provides better rolling resistance to the bike and *vice versa*, rough surface gives higher rolling resistance.

In terms of vibration excitation point of view, rough surface gives higher force excitation to the bike compared to the smooth one. Gravel, as the highest excitation, has many entities that can generate high force i.e. rocks, hard soils and many more. These things creates unequal roughness and unbalance surface density on the road, which therefore generates random excitation amplitude to the bike. This random surface, in turn, perceptively increases the uncomfort to the cyclist and increasing the vibration level at the same time.

It is then followed by soil as the scond highest. Similar with gravel, soil also contains so many entities that can generates high excitation force to the bike. However, the entities inside the soil is less than that in the gravel. The lowest vibration excitation is the cement pavement. It is quite understandable that cement road is the most comfortable road even for the pedestrian. It has no soil, gravel or other distrubances on its surface and provide low rolling resistance for the tire. It is then also clear that only small excitation occurred by this kind of surface and only low vibration is generated on the bike. Again, theory of Holzel *et. al.* [4] is applicable here.

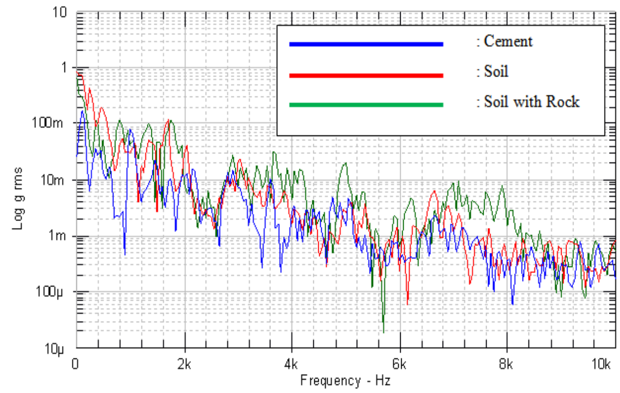

Figure 6 Effect of road surface (2.0 inch tire, cement pavement)

3.3 Effect Of Tire Size

The effect of tire size, meanwhile, is depicted in Figure 7. Tire size represents the contact area between the tire and the road. As the contact area is larger, the excitation force proportionally becomes higher. This can be seen in the Figure that the widest tire (2.1 inch) gives the highest vibration followed by 2.0 inch and 1.9 inch. Although the difference among the tires is only about 0.1 inch, but this apparently gives considerable changes on the vibration level.

The effect of size can be explained by the concept of the effect of friction on vibration given by Grudzinski and Kostek [10]. It implies that frictional force has direct impact and mutual interaction with vibration. The higher frictional force occurred on a system, the higher vibration generated. Yet, different friction creates different type of vibration. In our bicycle application, the friction force is simply produced from the contact between the tire and the road, as mentioned previously. As the tire is sliding on the road, a micro-scale friction force is generated adequately so that vibration occurs due to frictional-excitation force. Again, since the rotational speed is assumed to be harmonics, this friction force can also be assumed harmonics as well. The friction force is then harmonically generated as well as the harmonics vibration on the bike. As the tire size is larger, the friction force is higher proportionally and finally gives higher vibration excitation.

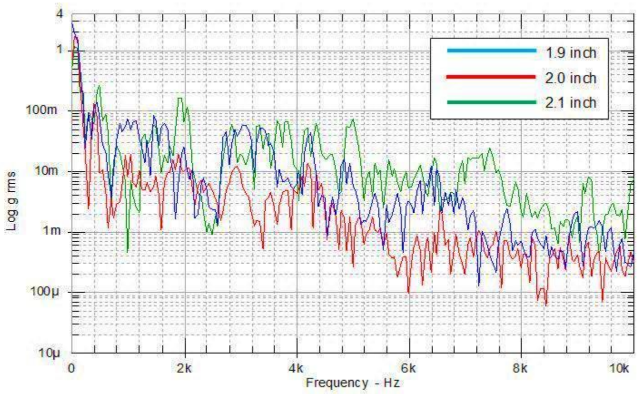

Figure 7 Effect of tire sizes (7 km/h speed, cement pavement)

3.4 Frame Damping Performance

As additional information, the comparison between front fork and seat post vibration is shown in Figure 8. The figure shows that the frame is able to reduce vibration from source (road, front fork vibration) to the seat post up to 100 mg. This is caused by the presence of suspension on the frame which has previously shown a superior performance in reducing vibration [8]. However, this information can be used for further investigations by testing the bicycle frame individually without suspension.

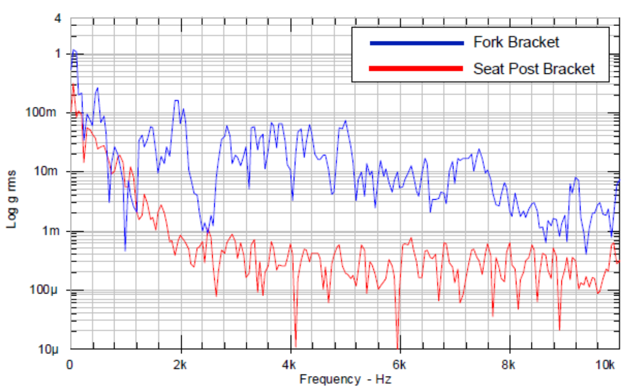

Figure 8 Frame damping (2.1 inch tire, 7 km/h, cement pavement)

4.0 CONCLUSION

The effect of road transmitted vibration on the MTB has been studied experimentally. As a conclusion, comfort level of a MTB determined by several matters. First, the increment of speed significantly increases vibration of the bike which eventually reduces the comfort level. Second, rougher road surface gives more excitation force to the bike and increasing rolling resistance of the wheel. Third, wider tire size produces wider contact area between the tire and road considerably which then increasing the bike vibration. Additionally, the presence of suspension system provides good performance of reducing road transmitted vibration.

Acknowledgement

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