STUDIES ON BRAKING-WIND UP VIBRATIONS OF MOTOR VEHICLE AND ITS SKIDMARKS

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INTRODUCTION

We often catch a glimpse of many types of skidmarks on the road surface in driving and most of these skidmarks are stamped with locked state of tyre by the motor vehicle emergency braking. They sometimes tell us a great deal about the running situation of its motor vehicle.

When running wheels are locked up instantaneously with emergency braking, hop up phenomena of body which sometimes called judder[1] more or less occur on rear suspension system.[2] Especially, in the case of 4 wheel vehicles equipped with suspension system of leaf springs, a wind up vibration-one of hop up phenomena-is produced by tortion of wheel axis and accompanied with intermittent skidmarks on road surface.

As far as we know, there are very few reports[3][4] on this problem and little is known about the mechanism related to this phenomenon. Then we have observed this phenomenon using models and actual cars.

EXPERIMENTAL PROCEDURE AND RESULTS

In order to know the general conception about a wind up vibration phenomenon and the intermittent skidmarks stamped on road surface, we carried out some tests using an actual car as shown in Fig. 1. This car is equipped with 4 drum brakers but has no servo system. In these tests, the vehicle brake pedal is powerfully hitted with a driver's foot at an arbitary speed between 30–60 km/h (8.3–16.7m/sec) and the period of right rear wheel vibration is measured by 72 frames/sec movie camera. Some examples of the result are shown in Fig. 2. From these data, it became clear that the wind up vibration period is nearly constant through braking operation from start to the full stop and moreover, it is likely to be constant, independent from the initial speed. The period

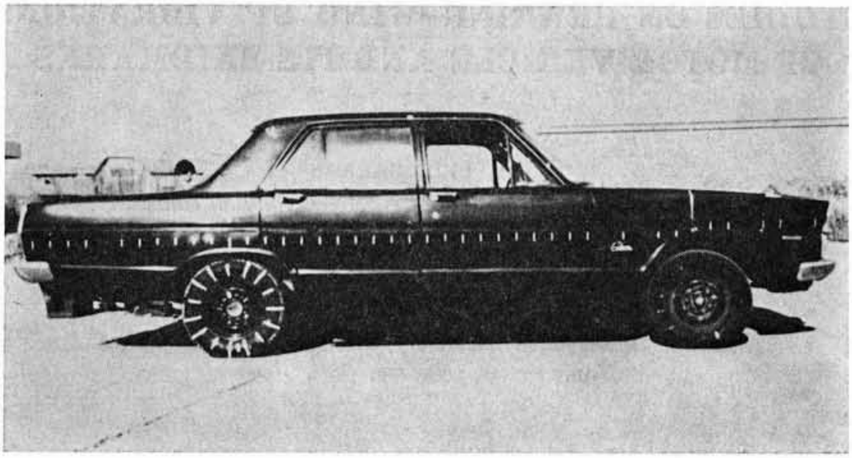

Fig. 1 Side view of the test car.

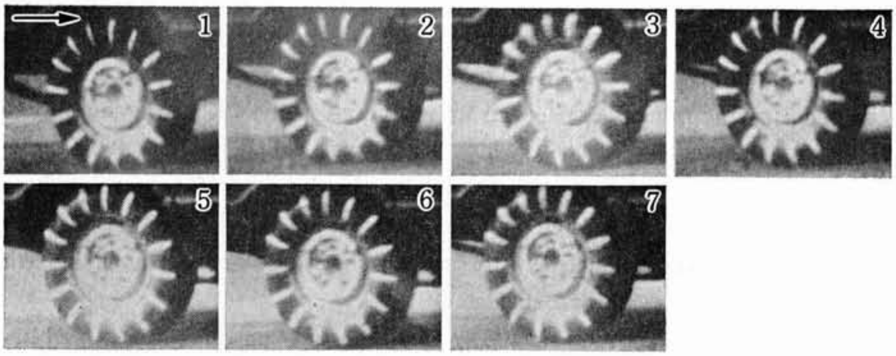

Fig. 2 Vibrating behaviors of the actual-car's rear wheel in period.

of this test car is ca. 0.09 sec. Examples of the test car-skidmarks are shown in Fig. 3-1 to Fig 3-3. The intervals of adjacent skidmarks are plotted against the period in Fig. 3-3. The length of skidmark between **w** and **b** in Fig. 3-2 indicated by No. 1 and No. 22 in Fig. 3-3 are exactly detectable with unaided eyes and dim pattern of skidmarks are recognized around a point **a**, but its exact length could not be measured from the pattern.

Model tests are tried qualitatively to clarify the relationship between wind up vibration period and vehicle stopping initial speed, and the process of tyre landing during the vibration. According to the data from experiments and literatures, 6 kinds of parameters controlling the wind up vibration may be considered. And 3 non-dimensional parameters relating this system, denoted by π_i are obtained by dimensional analysis. These basic parameters and non-

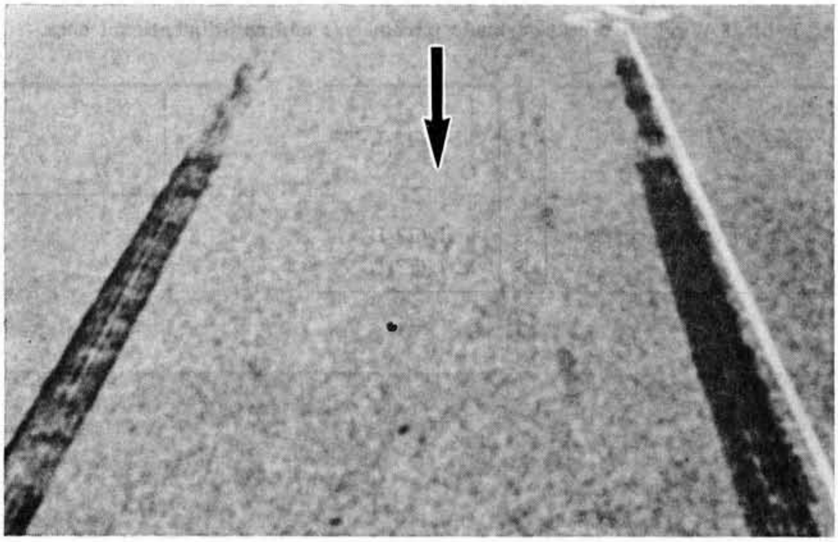

Fig. 3-1 An intermittent skidmark, initial speed: 58.1km/h (15.1m/sec)
The arrow ↓ indicates the test car-running direction.

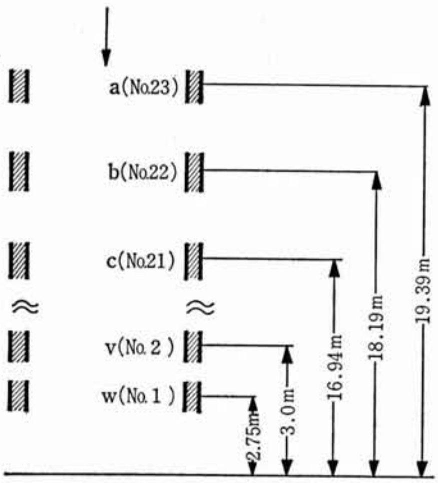

Fig. 3-2 Schematic diagram of skidmarks by the rear wheels in Fig. 3-1.

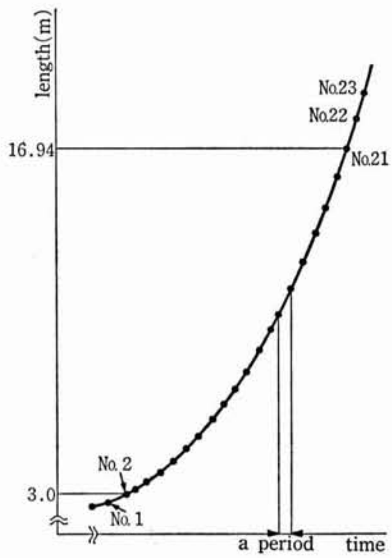

Fig. 3-3 Skidmark length in Fig. 3-1 versus the period.

dimensional ones are tabulated at Table 1. Generally, phenomena having equal numbers of π_i are all similar from the dynamical point of view. Then, in this model tests, it is necessary to make models whose π numbers are equal to the one of the test car-rear suspension system of prototype. Tentatively made four

Table 1 Wind up vibration-basic parameters and non-dimentional ones.

(1)

length	l	L
moment of inertia	I	M·L/T²·L·T²
angle	θ	O
time	t	T
rotational spring constant	k_F	M·L/T²·L
torque	F	M·L/T²·L

(2)

π_1	t^2k_F/I
π_2	θ
π_3	t^2F/I

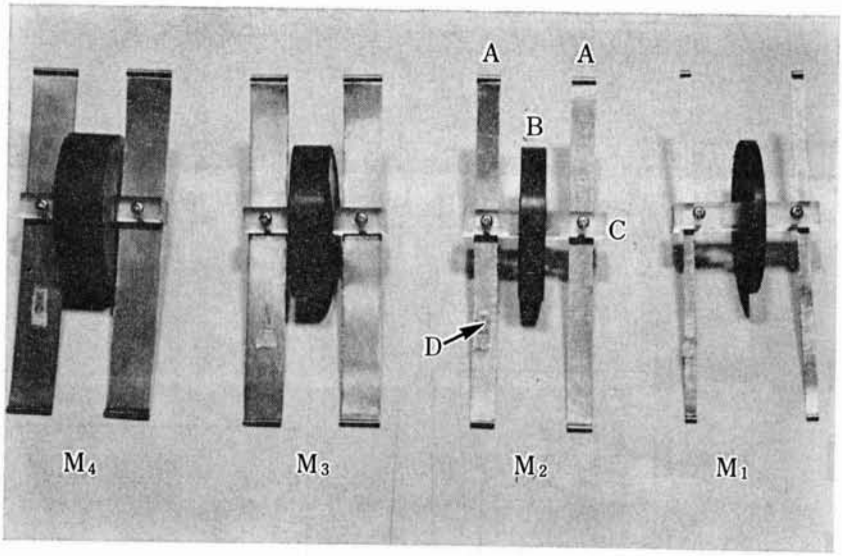

Fig. 4 Overall view of the models M_1, M_2, M_3, M_4.
A : spring B : rubber cylinder, 5cm dia.
C : shaft D : strain gauge

Table 2 Model's and test car's characteristic values.
* : measured value

	Rubber cylinder		Shaft		Spring	Wheel tyre differential gear device housing		
	weight (gf)*	moment of inertia (gf·cm·sec²)	weight (gf)*	moment of inertia (gf·cm·sec²)	rotational spring constant (gf·cm/rad)	weight (gf)*	moment of inertia (gf·cm·sec²)*	k_F/I
M_1	19.2	0.109	10.8	4.3×10^{-3}	2.55×10^3			2.25×10^4
M_2	41.2	0.234	10.9	4.36×10^{-3}	5.09×10^3			2.14×10^4
M_3	66.2	0.376	11.0	4.36×10^{-3}	7.64×10^3			2.01×10^4
M_4	79.4	0.451	10.6	4.24×10^{-3}	10.2×10^3			2.01×10^4
test car					15.4×10^6	103×10^3	20×10^3	7.7×10^2

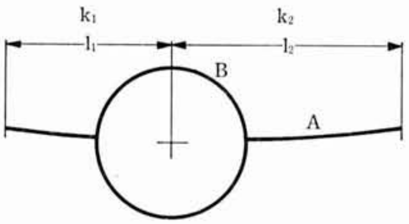

Fig. 5 Schematic diagram of model spring.
A : spring B : tyre

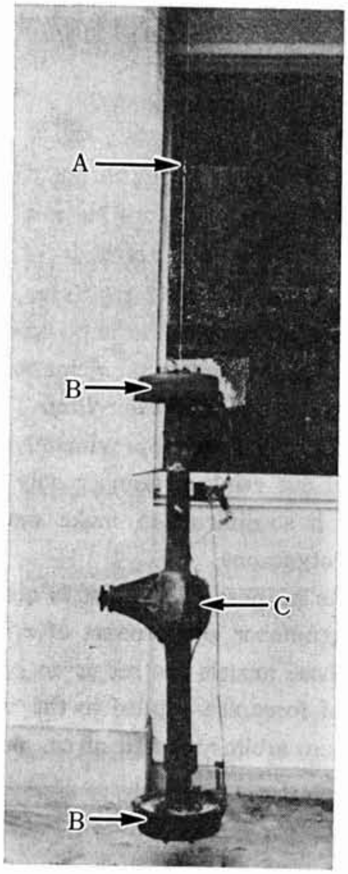

Fig. 6 Measuring method of moment of inertia with respect to an axis of wheel system of test car.
A : wire B : rotating drum
C : gear device housing

Table 3 π_1 numbers of models and test car.

	Model				Proto-type
	M_1	M_2	M_3	M_4	
π_1	17.4	19.9	17.0	20.1	6.2

kinds of models as shown in Fig. 4 are prepared. Parts **A** in Fig. 4 consists of 2 strips of narrow phosphor bronze plate (20×0.5, 15×0.5, 10×0.5, 5×0.5mm in cross section) and corresponds to the leaf spring system of the prototype. The rubber cylinder **B**, which corresponds to the total tyre system including wheel and differential gear housing etc of the prototype, has no-freedom of motion about a shaft **C**. The model and prototype characteristics are tabulated at Table 2. Rotational spring constant denoted by k_F in Table 2 are calculated by equation (1)[5]

$$k_F = kl^2 \frac{4(1+K\lambda^2)}{(1+K)(1+\lambda)^2} \quad (1)$$

where $\lambda = l_1/l_2$

$K = k_1/k_2 = 1/\lambda^3$

k : spring constant of leaf spring

sub indexes 1 and 2 show front and back side of leaf spring respectively (Fig. 5)

and moment of inertia I with respect to the total system including the differential gear device and its housing, tyres and wheels of the car are obtained by the method shown in Fig. 6. π_1 numbers of the models and the test car are tabulated in Table 3. As is evident from Table 3, π_1 numbers of 4 models and the one of the test car have approximately similar values. Thus these model tests are carried out using π_1 number only due to the following reasons;

(1) it is so difficult to make models whose π numbers strictly equal to the prototype one,

(2) the purpose of the test is qualitatively analysis of a wind up vibration,

(3) π_3 number is a product of π_1 and π_2.

These models are set at an equipment as shown in Fig. 7 and some magnitude of force are applied to the rubber cylinder to vibrate about the shaft **C** with an arbitary speed of ca. 50–400 cm/sec by means of the endless emery

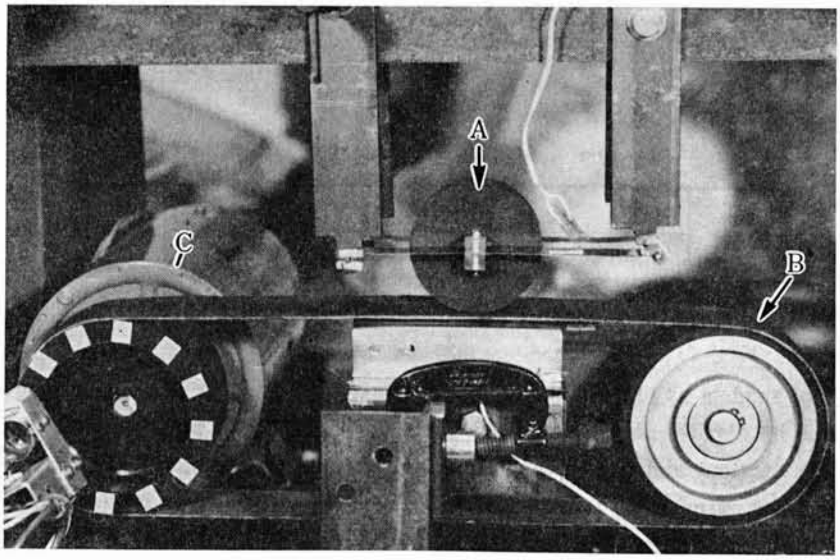

Fig. 7 Overall view of the modeling test apparatus.
A : model
B : endless emery paper
C : speed variable electric motor, 0–1800rpm, 200watt.

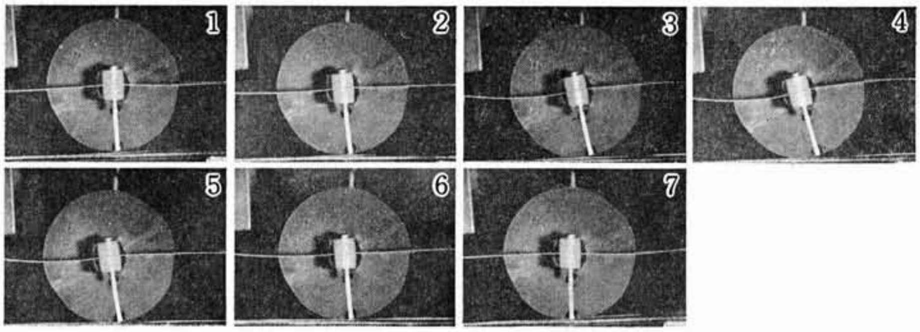

Fig. 8 Vibrating behaviors of a model M_2 in period.

Table 4 Wind up vibration-periods of models at constant emery paper speed 80.1cm/sec.

	Model			
	M_1	M_2	M_3	M_4
speed (cm/sec)	80.1	80.1	80.1	80.1
period (sec)	.0278	.0305	.0291	.030

paper (JIS-♯60), **B** in Fig. 7. The vibrating motion of a model is picked up by the strain guage glued on the leaf spring **A** and observed with stroboscope. Some examples of its motion are shown in Fig. 8 and their periods are in Table 4. From the results of the experiment, it is clarified that;

(1) the difference of periods between the models are very small,

(2) when tangential direction at a bottom point of vibrating rubber cylinder coincides to the direction of running belt of emery paper, the rubber cylinder come in touch with the emery paper.

In regard to the relationship between the period and the paper speed, the M_2 period is measured changing the speed and its results are shown in Table 5. As is evident from Table 5, period is nearly constant, independent of the speed of emery paper.

Wind up vibration periods are measured on passenger cars and light trucks

Table 5 Period of model M_2 versus emery paper speed.

	Model M_2						proto-type
speed (cm/sec)	80.1	106.8	160.2	213.6	267.0	320.4	0–1500
period (sec)	.0323	.0343	.0343	.0341	.0344	.0348	.09

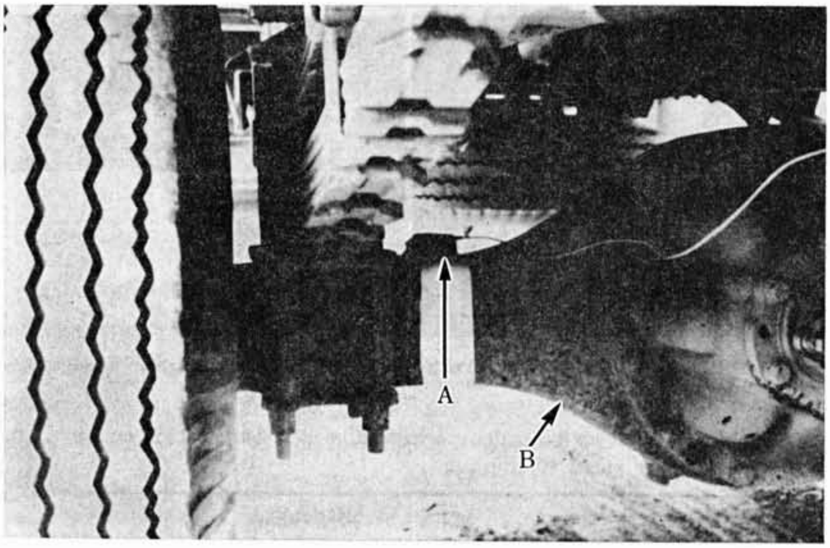

Fig. 9 50-Gravity acceleration pick up apparatus equipped on the differential gear device housing.
A : pick up apparatus
B : gear device housing

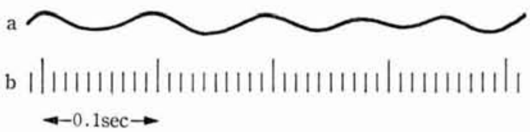

Fig. 10 An example of electromagnetic data.
a : wind up vibration
b : time

Table 6 Some examples of wind up vibration period of commercially available cars.
A : passenger car 2000cc.
B : passenger car 12000cc.
C : passenger car 2000cc.
D : light truck 1500kgf.
E : light truck 2000kgf.
F : medium truck 4000kgf.
G : passenger car 2000cc (test car).

	A	B	C	D	E	F	G
period (sec)	.072–.077	.084–.086	.098–.107	.088–.089	.07–.08	.09–.1	.09

whose rear suspensions have leaf springs, using strain gauges glued on the leaf spring or 50-Gravity acceleation pick up apparatus equipped on the differential gear device housing as shown in Fig. 9. The measuring direction of this acceleration pick up system is taken to the running direction of vehicle. An example datum read from electromagnetic recorder is shown in Fig. 10 and the periods of the vehicles are tabulated in Table 6. This period is mean value in braking operation with ca. 40km/h (11. 1m/sec) initial speed to the full stop. As is evident from the results of these data, they are characteristic one of vehicles and are nearly constant values during braking respectively.

DISCUSSION

As is evident from Table 3, each model-their π_1 numbers are almost equal, and it also nearly agrees with the one of the test car. So it is apparent that the relationship between the test car-period and the vehicle stopping initial speed, and the tyre landing processes during the wind up vibration may be simulated by the models. Then from the results of the data tabulated at Tables 4 and 5, the period of the wind up vibration which occurred on the rear suspension with leaf spring during rapid braking are constant with regard to the vehicle stopping initial speed. And moreover the period is a function of the ratio of the moment of inertia with respect to the wheels and the drive shaft system to the rotational spring constant of leaf spring, so the wind up vibration period becomes constant value for the reaf suspension system whose ratio is same value, independent of the types of vehicle.

In regard to the skidmarks layed down by the emergency braking wind up vibration on the road surfaces, the pattern at the beginning is generally dim because of the initial vibration is irregurally disturbed. And in many cases, the patterns and the intervals between the adjacent short skidmarks become clear except a first skidmark, for example No. 23 skidmark at Fig. 3–2. Then we may define that initial velocity just after rapid braking is of the mean velocity in a finite short time at a point which is a certain instance before a point **b** in Fig. 3–2. This short time may be assumed the wind up vibration period and that certain instance may also be assumed a sum of the wind up vibration period and the time from the brake start to the wheel lock up. And the distance of a car slipping in the finite short time could be calculated approximately from the skidmark which can be detected with unaided eyes. Using these method, the vehicle speed 56. 8km/h is gained from the data shown in Fig. 3 and 56. 4 km/h from the total skidmark length No. 23 and No. 1 in Fig. 3 by the method widely used. In this case, real speed of the vehicle is 58. 1km/h. Then, these

3 values of speed are nearly coincide with each other, and it can be considered that this vehicle speed calcurating method from the wind up vibration skidmarks is reasonable. For example, a vehicle wind up vibration skidmarks on road surfaces after a traffic accidents, even the case as unnaturally stopping by collision with other car or some solid substance, it is possible to clear its initial speed before braking from a part of the intermittent skidmarks.

From Table 6, the periods of **A**, **B**, **C**, **D**, **E**, **F** vehicles are same values, so it is considered the ratio k_F/I of these cars are nearly equal.

CONCLUSIONS

Laboratory tests for wind up vibration, one of hop up phenomena which generally occured during emergency braking at rear suspension system and its intermittent skidmarks, are carried out using passenger cars, trucks and models. And the following conclusions may be drawn from the results of this work.

(1) Generally, rear wheel suspension system with leaf springs has more or less wind up vibrations by emergency braking and the wheel vibrates around its axles with constant period independent of the initial speed before braking. And numbers of intermittent skidmarks layed down on road surfaces are nearly equal to one of vibration in locking. Then automobiles can run with the constant time through the arbitary 2 short skidmarks without a relationship of its length. Then using these intermittent skidmarks, motor vehicle initial speed before braking can be cleared by a few intervals of the short skidmarks and the rear wheel wind up vibration period. Moreover, considering the time from begining of rapid braking to complete locking, the calcurating accuracy may be expected to increase.

(2) When the ratio k_F/I is same about all kinds of motor vehicles, it should seem the wind up vibration was nearly constant, independent of the kinds of motor vehicles: passenger cars or trucks. We obtained the period 0.07–0.107 sec.

(3) Tyre landing process during braking wind up vibration is as follows. Right rear wheel seen from the above are landing when it rotaes clockwise and takes off road surface when it rotates counter-clockwise as seen from above. The above mentioned phenomenon are repeated periodically from brake start to vehicle full stop.

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