(1) The maximum impact torque applied on the prime mover during heavy digging work was generally 100~240% of the maximum torque produced statically by the prime mover. This percentage was smallest in the case of the torque converter system and was largest in the case of the direct drive system.

(2) The maximum impact torque applied on the prime mover during swing acceleration and deceleration was generally 60~160% of the maximum torque produced statically by the prime mover. This percentage was also smallest in the case of the torque converter system.

(3) The maximum impact torque applied on the prime mover during start of travelling was generally 50~100% of the maximum torque produced statically by the prime mover, and the value of maximum impact torque was largest in the case of the torque converter system.

(4) The fluid coupling is ideal for the drive system of power shovels because the impact load can be reduced without reducing the work rate.

(5) The torque converter system is especially effective for heavy digging work because it can produce a large power and also reduce the impact load.

(6) The motor having drooping characteristics is also suited for the drive system of power shovels.

(7) The impact torque applied on the prime mover during digging and swing operations was found to match quite closely the values computed from the speed fluctuation of the prime mover's shaft and swing.

Reference


621-515:621. 7:629. 113-59:658. 542. 3

Human Factors in Braking and Fade Phenomena for Heavy Application

— Problems to Improve Brake Performance* —

By Kazuhiko Aoki**

Ability of human being as an operator of braking mechanisms was investigated. Effect of posture on foot and manual force, delay and transient in handling brake pedals or sticks, and experimental formulae for these were discussed. For service brakes, 20kg for passenger cars, 30kg for commercial vehicles may be desirable. It will take less than 1.2 and 1.4 sec for 80% of males and females respectively from stimulus to full application. Posture of passengers and transient of application has prominent effect on riding comfort at braking.

Using actuating mechanism developed for this test, fade phenomena during braking on the road and at the dynamometer were observed. Effect of lining characteristics, shoe type, and thermal condition of brake mechanism were calculated using analogue computers.

1. Introduction

As the velocity of automobiles increases, brake performance should be improved simultaneously to secure ease of control and safety. Problems here are: (1) to increase brake efficiency, (2) delay of action is more critical at high speed, (3) decrease of brake force known as "fade" in heavy vehicles and high speed cars should be prevented, (4) in certain cases, auxiliary or retarding brakes are necessary to assist main brake systems (5) locking of wheels and uneven braking for right and left wheels should be prevented to keep directional and control stability.

* Received 5th December, 1959.
** Research Fellow, Transportation Technical Research Institute, Ministry of Transportation, Mitaka, Tokyo.
This paper deals mainly with the human factors in relation to items 1, 2, and also with experimental and theoretical results of fade phenomena.

### 2. Human Factors at Braking

#### (1) Pedal force

For service brakes, foot is usually applied for actuation. Pedal force necessary to obtain 0.6 g of brake efficiency for the vehicles tested is shown in Fig. 1. Some of the vehicles required pedal forces as high as 100 kg.

In order to determine the acceptability of these values, we measured the characteristics of human output of pedal effort using test rigs shown in Fig. 2. A few subjects were selected for tests with various parameters, and a number of subjects were used for tests with fixed parameters.

An example of the relation of pedal force versus hip joint angle $\alpha$ and knee angle $\beta$ is shown with experimental formula in Fig. 3. For statistical results (Fig. 4), we scaled the ordinate according to the cumulative frequency for the normal (Gaussian) distribution. If the distribution is normal, therefore, the curve will be a straight line, and the length of abscissa corresponding to 50 to 15.9 % gives standard deviation $\sigma$. Subjects selected for these tests were: 60 male drivers, 54 high school girls 16 years of age (which is the lower age limit for driver's licence in Japan) and 37 handicapped adults of both sexes.

From Fig. 4, if we adopt 70 kg for the upper limit of pedal force, this can be attained by 80 % of male drivers. This value, however, will be
realized only with enormous physical effort. If we like to operate with ease, this force should be reduced to the neighbourhood of 40 kg. For passenger cars the value may be 30 kg at most, and 20 kg preferably.

Handicapped subjects consisted of polio and disabled limb victims. This datum is mainly for the legs unhurt, but some subjects could provide 70 kg, and drive safely with artificial legs.

If pedals were arranged to operate with the driver's heel (on the floor,) it will be effective to reduce fatigue and delay, but pedal force in this case should be under 20 kg.

(2) Manual pull

Fig. 5 shows manual force for various wrist positions. A subject was seated on a chair holding the lower body in position. Force pick up was located at points indicated by •. The subject gripped this pick up, pushed or pulled it in every direction. This force is shown by polar coordinates using each measuring point as origin. The result shows that the maximum force for each position tends to a point indicated by ○ in Fig. 5. The relation of this maximum force with distance \( r \) and angle \( \theta \) is shown in Fig. 6.

Thirty kg for males and 20 kg for females may be the limit to operate sticks easily (Fig. 7). For parking brakes, much more stick force was necessary for certain cars (Fig. 8). Moreover, ample allowance is necessary, since by loosing the hold, brake force will be reduced by 20 to 70%
due to the action of ratchet.

(3) Reaction time

Fig. 9 is the result of reaction time for subjects seated on the rigs shown in Fig. 1. Subjects were requested to remove his right foot from the accelerator pedal and operate the foot brake as soon as the red lamp was lighted. Both pedals were fixed, and time interval from the stimulus to the departure of foot from the accelerator pedal was considered to be the reaction time. Magnitude of pedal force to operate the brake had little effect on the reaction time.

(4) Transfer time

Time necessary to transfer the foot from accelerator to brake pedal, herein called transfer time, is the function of posture and method of transfer. It we lift our foot from the former pedal and press the latter perpendicularly (case A), transfer time is longer compared with the case of transfer by the shortest distance (case B).

Experimental formulae for these cases are as follows:

$$T = 0.20 \left[ 1 + \left( \frac{|H + 2.0|}{28} \right)^{1.06} + \left( \frac{L}{40} \right)^{1.44} \right]$$  \hspace{1cm} \text{(A)}

$$= 0.14 \left[ 1 + \left( \frac{|H + 1.0|}{19} \right)^{1.44} + \left( \frac{L}{40} \right)^{1.44} \right]$$  \hspace{1cm} \text{(B)}

where $H$ is the difference of pedal height which is positive when accelerator pedal is lower, and $L$ is pedal distance, both in cm.

In the case of change with the heel on the floor, the easiest method is to put the heel in the middle of two pedals ($\Delta$ in Fig. 10), and transfer time is also short then. Fig. 11 is the result obtained with pedal distance 15 cm, and no-
difference in pedal height.

(5) Transient of pedal force

This may be considered approximately as the delay of the first order, \[ F = F_0 / (1 + T_s) \], where \( F_0 \) is final force, \( T \) is time constant, and \( s \) the operator. \( T \) is small for the posture in which a high pedal force is to be expected. Result obtained from a subject in various postures is as follows:

\[ T = 0.09 \left[ 1 + \left( \frac{\alpha - 80}{65} \right)^{1.35} + \left( \frac{\beta - 80}{127} \right)^{1.85} \right] \]

Fig. 12 is the statistical result.

(6) Summary of braking action

Fig. 13 is the summary of the above results. If we pick up reaction time, transfer time, pedal force and time constant which could be attained only by 20% of the male subjects, the whole procedure may be as indicated by the upper broken line. It takes nearly 0.7 sec from stimulus to full braking for 20% of the male drivers, and 1.2 sec and 1.4 sec respectively for 80% of male drivers and females.

3. Fade

Brake force is generated by friction between brake lining and brake drum or disc. Coefficients of friction which play an important role here change with temperature, velocity, pressure, and history of application. For a high speed car at heavy braking, braking power is sometimes in the vicinity of ten times the engine output (Fig. 14). If, therefore, the brake is not cooled enough, fade due to temperature rise may be inevitable.

In order to test this phenomenon, the author designed a new input mechanism for brake testing and named it "Brake Actuator" (Fig. 15). Energy source for this rig is a pressure bomb. Nitrogen was used instead of compressed air for safety. Three hundred atm gas pressure was reduced to five atm or less by reducing valve, converted to

![Graph showing brake performance](image)

Fig. 13 Summary of braking procedure

![Graph showing power absorbed by brake](image)

Fig. 14 Power to be absorbed by brake

![Diagram of brake actuator](image)

Fig. 15 Brake actuator

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger car</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Truck</td>
<td>▼</td>
<td>▼</td>
</tr>
<tr>
<td>Bus</td>
<td>△</td>
<td>△</td>
</tr>
</tbody>
</table>
hydraulic pressure and supplied to the brake system of the car tested. It is possible to apply an initial input having a time constant of 0.006 sec minimum by opening the output valve.

Fig. 16 is the result obtained with an American passenger car, in which the car was braked from various initial velocities with predetermined input by the rig above. Minimum value of deceleration (fade) and deceleration at the time of complete stop (recovery) were plotted in Fig. 17 which the author names "F-R Diagram". Each curve in this diagram does not mean that phenomena will occur along this line, but indicates interpolation of the test results. If we apply oil pressure (equivalent to 32 kg of pedal force) which should give a car deceleration corresponding to 1.0 g (○) (if there is no fade) for the initial velocity of 32 km/hr, deceleration will decrease to 0.74 g (●) (fade) and will gradually increase up to 0.86 g (□) (recovery). For initial velocity of 120 km/hr, brake force was reduced to 27% of the original value for the same pedal pressure.

Another example of a European car has less fade as seen in Fig. 18. Continental car-builders in general have been more concerned with fade than American, but the latter have taken various means to suppress fade.

Fig. 19 is one of the results of brake dynamometer test. Inertia mass was arranged to duplicate the actual car condition. In this case there is practically no fade for the trailing shoe due to the flat temperature characteristics of the brake lining at relatively low temperatures.
In order to find out the effect of lining characteristics and shoe type on fade, the author tried a theoretical calculation using a low speed electronic analogue computer. Four types of lining (A to D, hypothetical) with different temperature characteristics were selected (Insert to Fig. 22).

With the same pedal force, i.e., same force applied to shoe tip, the brake force generated will be different for various types of shoes. This ratio is called the brake factor, and defined as: (brake force at the contact surface of lining with drum)/(shoe tip load). This factor varies with shoe dimensions in detail, but in general it has the tendency as shown in Fig. 20. Those having more self-energizing effect, (e.g., leading, duo servo, etc.) are more sensitive to change in the coefficient of friction of the lining. If we do not use a lining with considerably flat temperature characteristics, those types are liable to cause prominent fade or unbalance of braking force for right and left wheels, which will result in unsteady motion of the car. Temperature rise, fade, and braking distance for various linings and shoe types were calculated for the car with G.W. 1600 kg, lining area 233 cm² (for each wheel), and drum area 350 cm² (ditto). (Figs. 21, 22.)

For emergency stops in which a very little time (in the order of seconda) is necessary, heat transfer from outer surface of drum has little effect on fade except for a very high speed or heavy car. Improvement of heat conductivity of lining also is not very effective, especially when the lining area is relatively small as in the case of disk brakes. When a drum or disk material of high thermal conductivity is used, it will reduce the maximum temperature of lining, but again we can not expect too much from it.

For descents on a long hill, on the other hand,
when brakes are applied for a long time (in the order of tens of minutes), improvement of thermal conductivity of drum or disk material, and heat transfer to air in the case of drum type, are quite effective. For disk brakes, disks are usually sandwiched between linings on both sides, heat emission, therefore, is chiefly from the surface of disk which is at the highest temperature in this vicinity, making cooling efficiency relatively high. Ratio of lining area to disk area is more important than in the case of drum type; if it is too large, the disk is thermally inferior to the drum in case no compensating means is adopted.

4. Retarders and other problems

Increase of vehicle speed and weight made it difficult to prevent fade with brake mechanisms and materials we have at hand. Retarders have been developed as a remedy for this and in certain parts of Europe its use to specified cars are enforced by the law. Braking force of retarders increases with speed, thus has more or less self-governing characteristics.

Retarders of exhaust, hydraulic, and eddy current type have been applied in Japan. Fig. 24 is an example of hydraulic type retarder with a turbine fixed or rotated in the reverse direction. For the hydraulic and eddy current types, heat generation limits their capacity. For very high speed cars aerodynamic brake like dive brakes in jet planes had been developed.

Delay in transmitting brake force is important for air brakes, especially for trailers, in which case certain measure to prevent delay is necessary. In case of oil brakes, increase of rigidity of oil line and improvement of high temperature characteristics of brake oil is necessary.

To make full use of the braking ability of tyre, and also to prevent skidding, automatic balancing of distribution of braking force to axle load, or anti-slip device should be adopted.

5. Conclusion

Improvement of high speed performance of brakes may be realized by matching the design to the ability of drivers. Actuating forces should not be excessive, and time delay should be compensated by proper mechanism, especially for large units.

Fade may be avoided in three ways; (1) to improve cooling of brake mechanism, (2) to make the temperature characteristics of lining material as flat as possible, (3) by the employment of auxiliary brake system such as exhaust, electric, hydraulic or aerodynamic brakes in case the above methods can not solve the problem.

Positive characteristics of a car, i.e. the acceleration performance should balance with retarding performances, and preferably there should be only one control for positive and negative acceleration. In the near future, brakes may be applied automatically when the car is approaching an obstacle or other car too closely, and the transient of retardation should be such that there will be no jerk which is dangerous or uncomfortable to occupants. Even a small step toward this goal will improve safety.