CONSTRUCTIONAL AND TRIBOLOGICAL ANALYSIS OF MOTOR VEHICLE BRAKE SYSTEMS

K. Dezső, I. Emőd, A. A. Mubarak, Gy. Lipovszky, L. Tóth and F. Varga

Department of Machine Industry Technology and
Department of Vehicle Engineering
Technical University, H—1521 Budapest

Received September 3, 1987
Presented by Prof. Dr. K. Bakondi and Prof. Dr. L. Lévai

Abstract

Under certain circumstances it occurs that the front axles of the brake systems of lorries and buses do not work properly. This abnormal operation can also present itself in an unfounded increase of the forces in the right-hand or left-hand brake system. This unfounded brake force increase can result a steer deflection and, at the very worst, it can cause accidents. An abnormal increase in the brake force can appear as early as after running 500...3000 km.

This paper is an analysis of the constructional and tribological aspects of this abnormal brake force increase.

Constructional analysis of simplex wheel-brake systems with fixed anchor pin

In order to simplify maintenance and assembly techniques, fixed anchor brake shoes of simplex wheel-brake systems are more and more frequently manufactured with open-eye (Fig. 1) [1].

In the dynamic analysis of open-eye brake shoes it is very important to take the direction of the force acting on the pin into consideration. A basic requirement is that the force acting on the pin should act within the area of bearing of the eye, otherwise the eye leaves the pin. This leave can be observed in the trailing brake shoe.

The relations determining the amount and direction of the reaction force can be derived on the basis of Fig. 2.

The force equilibrium equations:

$$\Sigma X_i = 0, \quad S\cdot\cos\gamma - \frac{\mu}{\mu(\sin\alpha_2 - \sin\alpha_1)}(A \pm \mu D) + F\cdot\cos\delta = 0$$

$$\Sigma Y_i = 0, \quad S\cdot\sin\gamma - \frac{\mu}{\mu(\sin\alpha_2 - \sin\alpha_1)}(D \mp \mu A) + F\cdot\sin\delta = 0.$$

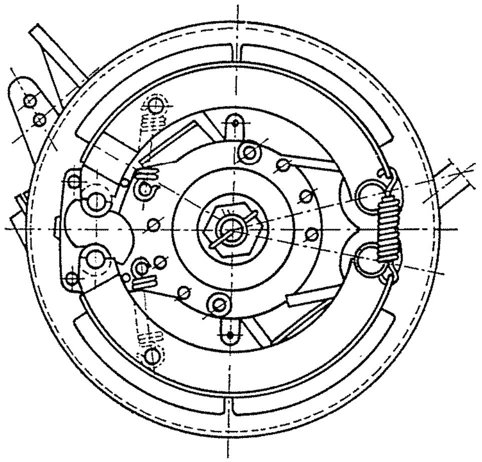

Fig. 1. Simplex wheel-brake system layout

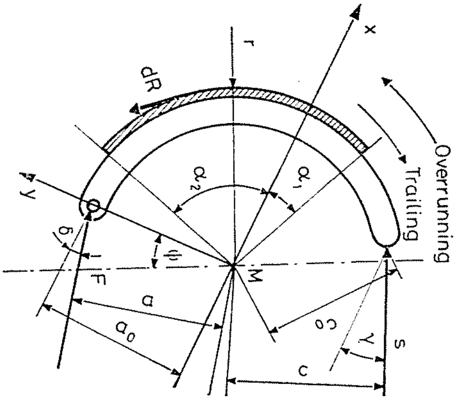

Fig. 2. Diagram of the brake system force action

The momental equation:

$$\Sigma M_M = 0, \quad S \cdot c + rU - a_0 \cdot F \cdot \cos\delta = 0$$

where:

$$A = \int_{\alpha_1}^{\alpha_2} \cos^2\alpha \, d\alpha$$

$$D = \int_{\alpha_1}^{\alpha_2} \sin\alpha \cdot \cos\alpha \, d\alpha$$

and

$$U = \int_{\alpha_1}^{\alpha_2} dr$$

where dR the elemental friction force.

Performing the integrations, we obtain the following constants:

$$A = \frac{1}{4}[\sin 2\alpha_2 - \sin 2\alpha_1 + 2(\alpha_2 - \alpha_1)],$$

$$D = \frac{1}{2}(\sin^2 \alpha_2 - \sin^2 \alpha_1).$$

If the equations are solved for $\frac{U}{S}$, $\frac{F}{S}$ and δ:

$$\frac{U}{S} = \frac{a_0 \cdot \cos \gamma + c}{\dfrac{a_0(A \pm \mu D)}{\mu(\sin \alpha_2 - \sin \alpha_1)} \mp r}$$

and

$$\delta = \operatorname{arc\,tg} \frac{\dfrac{U}{S} \cdot \dfrac{D \mp \mu A}{\mu(\sin \alpha_2 - \sin \alpha_1)} - \sin \gamma}{\dfrac{U}{S} \cdot \dfrac{A \mp \mu D}{\mu(\sin \alpha_2 - \sin \alpha_1)} - \cos \gamma},$$

$$\frac{F}{S} = \frac{c \mp r \dfrac{U}{S}}{a_0 \cos \delta},$$

where: "c" is the distance between the action line of force S and point M, thus:

$$c = \frac{c_0}{\cos \psi} \cdot \cos (2\psi - \delta)$$

"a" is the distance between the action line of force F and point M, thus $a = a_0 \cdot \cos \delta$.

All the other data depend on the geometry of the brake system.

In the relations the upper signs refer to the overrunning brake shoes, the lower signs go for the retailing ones.

The S force holding the shoes against the drum can be calculated by means of the following relation:

$$S = F_m \cdot \frac{l}{2e} \cdot \eta_{\mathrm{mech}},$$

where F_m = the force transmitted to the brake adjusting lever by brake cylinder
l = the length of the brake adjusting lever,
e = the radius of the involute base circle,
η_{mech} = the efficiency of mechanical gearing.

If the force holding the shoes against the drum is known, the F reaction force originating in the brake support pin, and its value and its direction too, can be calculated; if we know the S force, the F/S ratio can be obtained.

On the basis of these relations the values of U/S, δ, and F/S were determined as a function of the change of the frictional coefficient between the brake lining and the brake drum, as well as the F values of the reaction force acting on the brake support pin, as a parameter of the load on the engine. The basic data of the wheel-brake system studied as a model are as follows:

$$C_0 = 125{,}5 \text{ mm}$$

$$\gamma = -0.1487 \text{ rad}$$

$$\psi = 0.1739 \text{ rad}$$

$$a_0 = 156 \text{ mm}$$

$$\alpha_1 = -0.9425 \text{ rad}$$

$$\alpha_2 = 1.117 \text{ rad}$$

$$r = 200 \text{ mm}$$

$$\eta = 0.85$$

$$r_g = 13 \text{ mm}$$

radius of brake shoe's roller

$$F_M = 1408\ N$$

$$l_0 = 130 \text{ mm}$$

The following results have been obtained:

μ	U/S	δ	F/S
0.2	0.308	0.982	0.580
0.25	0.365	1.129	0.583
0.3	0.416	1.257	0.596
0.35	0.462	1.367	0.617
0.4	0.504	1.460	0.641
0.45	0.543	1.538	0.668
0.5	0.578	1.537	−0.696
0.55	0.610	−1.481	−0.724
0.6	0.640	−1.433	−0.752

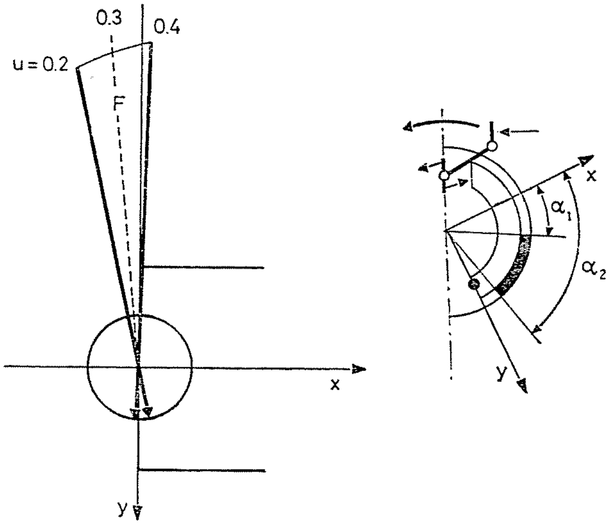

Fig. 3. The amount and direction of relative forces acting on the brake pin

On the basis of these data the relative amount and the direction of the force acting on the brake pin are demonstrated in Fig. 3.

It can be read from the diagram and from the table that if the value of the coefficient of friction is higher than 0.48, the pin can no longer support the brake shoe.

The value of the coefficient of friction between the brake shoe and the brake drum is normally between 0.3 and 0.4. The μ value can surpass the critical 0.48 if, e.g., some dirt gets in between the friction elements, or the frictional coefficient of the lining increases as a result of a change in temperature. The direction of the action force is unfavourably influenced by defects in the geometrical trueness of the brake drum, which may come into being during manufacturing, transportation or storage.

We have studied the effect of ovality, a fault in the geometrical trueness, in a phase of braking when, owing to ovality of brake drum, the brake lining bears against the drum near the anchor pin. In order to simulate the effect, we have decreased the angle of bearing of the brake lining and shifted it towards the pin without changing the other data.

The data changed:

$$\alpha_1 = 0.0698$$

$$\alpha_2 = 1.117$$

It can be seen that the value of the frictional coefficient belonging to the critical direction of the reaction force was significantly diminished. Sometimes a standard

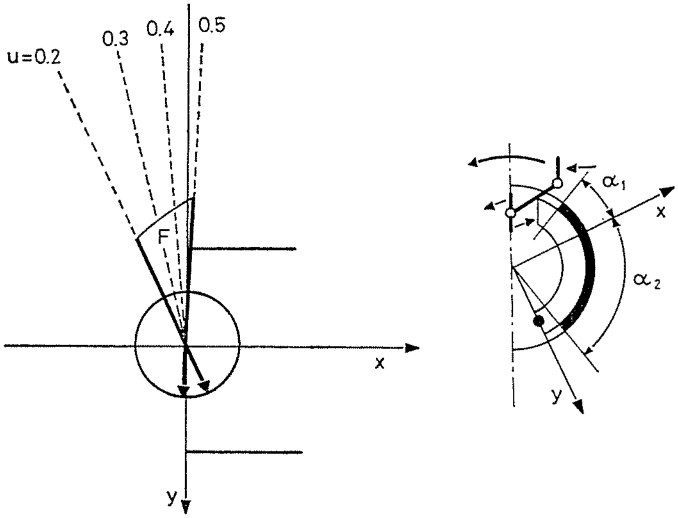

Fig. 4. The amount and direction of forces acting on the anchor pin after changing the angle of bearing of the brake lining

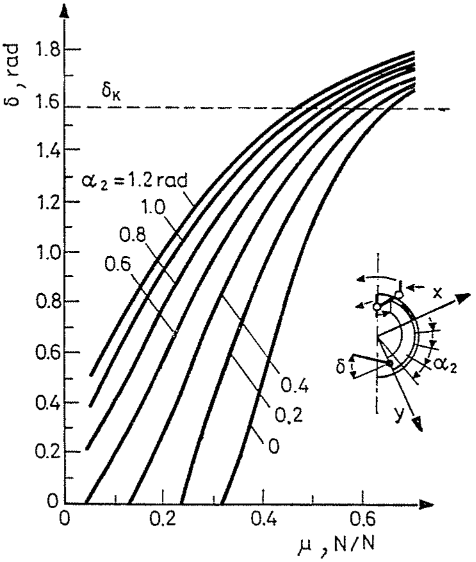

Fig. 5. The coefficient of friction, the relationship between δ and the α_2 angle

deviation occurring during the production of the friction lining material is enough to produce a μ value like this.

The effect of the bearing angles of the lining was analyzed by means of a model in which we changed the α_2 angle. The calculation results are presented in Fig. 5.

It can be seen very well from the figure that by increasing the value of the α_2 angle, the value of the frictional coefficient belonging to the critical direction of the reaction force is reduced.

In the foregoing we have assumed that the eye was open in the direction of the brake drum radius crossing the centre of the anchor pin, i.e., along the axis denoted y in the diagrams. The dash line drawn in Fig. 5. corresponds to this radius direction ($\delta_k = \pi/2$).

It can be read from the diagram that if the opening plane of the eye is a little shifted around the anchor pin centre, as shown in Fig. 6, the conditions that the shoe is supported against the pin, even under unfavourable circumstances, are fulfilled.

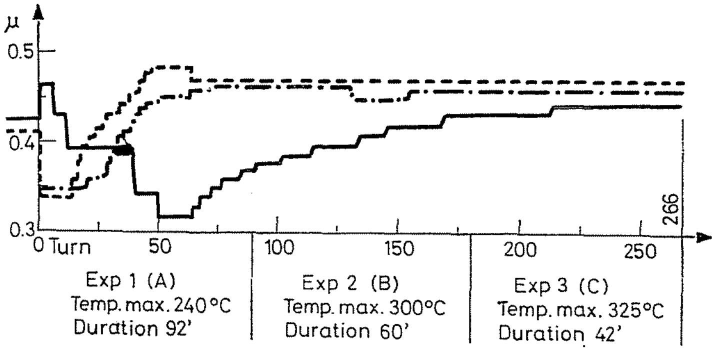

Fig. 6. The Cuna-Ransi $\mu - T$ diagram

Tribological analysis of the friction lining of brake systems

Friction linings of various synthetic resin-asbestos composition are widely used in the brake systems of lorries and buses. The $\mu - T$ diagram of this brake lining material determined by the Cuna-Ransi method is presented in Fig. 6. According to the diagram, the μ value changes as a function of temperature.

In Fig. 7 the $\mu - T$ diagram determined by a GAMF appliance is presented. According to the diagram, the frictional coefficient of the lining varies in the period of warming up and in the recovery period.

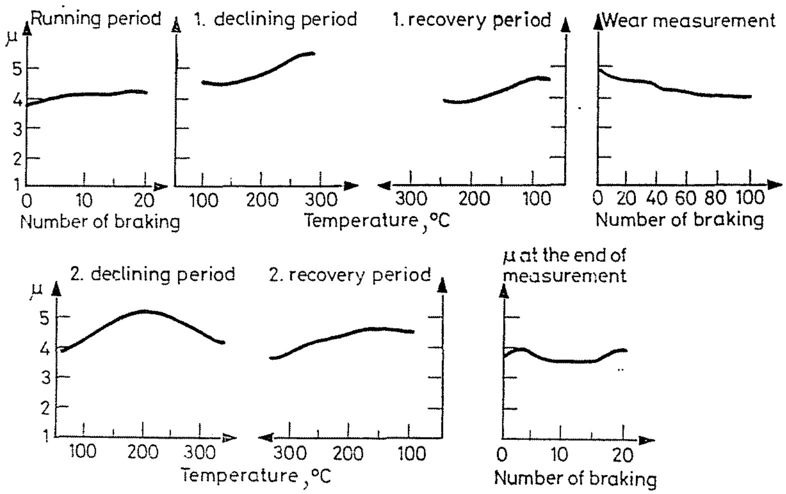

Fig. 7. The GAMF $\mu - T$ diagram

Characteristic properties of the synthetic resin-asbestos friction linings, which are advantageous from the point of view of application techniques, are as follows:

- good resistance to wear,
- good mean μ value,
- low production and row material costs.

Their disadvantages:

- relatively high degree of hardness and rigid construction,
- the value of μ increases as the temperature rises,
- considerable drum wearing effect.

These advantageous and disadvantageous properties are principally caused by the phenolformaldehyde synthetic resin bonding agent, which does not contain any internal softener. In the course of curing the synthetic resin takes up a brittle, rigid, space lattice structure. This space lattice structure is rigid and not capable of further deformation. Its rigidity increases as the temperature rises. The asbestos of the friction lining often contains slaty, marly, abrasive materials. The size of abrasive grains can range between 20 μm and several mm. These hard abrasive grains embedded in the synthetic resin wear the brake drum.

The wear of the brake drum caused by various abrasive asbestos materials is demonstrated by the following data [2].

Asbestos quality	Wear mm/kwh	The roughness of the worn surface Ra, μm
High purity	0.72	0.1 ...0.125
+20% baryte content	3.72	0.27...0.35
+20% marl content	0.83	0.1 ...0.125
Asbestos of commercial purity	1.32	0.2 ...0.25

The mechanism of friction lining failures

During braking, for various reasons, e.g. as a result of the local strains of the brake drum and shoe, overpressure can develop at certain parts of the friction lining surface.

The rigid friction lining of synthetic resin-asbestos composition can not follow these local increases in the pressure with local elastic strains. Thus, these places warm up intensively. As a consequence of these changes, the frictional coefficient of the lining increases. This again results in further warming up and in the extension of the area of increased local temperature. Thus the value of the frictional coefficient in these warmed up areas can increase from the original 0.38...0.40 value to reach 0.48...0.50, or even higher values.

As a consequence of this increase in the coefficient of friction, the direction and value of the reaction forces acting on the anchor pins of the brake system can change.

As can be seen from Fig. 3, if the coefficient of friction is between 0.48...0.50, the direction of the force between the pin and the brake shoe reaches the boundary position where the open-eyed brake-shoe support can no longer resist the lifting force. In consequence of this effect, the brake shoe is shifted and leaves the pin. Thus the brake shoe becomes a floating brake shoe. Since the value of the *F* force is high and its lateral component is also significant, self-closing is brought about.

Self-closing goes on increasing the surface pressure of friction lining and results a local, striped destruction of the lining surface.

Thus, if self-closing occurs, it can be caused by the local specific pressure increase.

This pressure growth can result from several factors. Factor like these are, e.g.:

- fault in the geometrical trueness of the friction lining, its surface roughness and inhomogeneity;
- fault in the geometrical trueness of the brake shoe, its deflection, warping and inhomogeneous structure;
- fault in the geometrical trueness of the brake drum, its inhomogeneous structure and its own internal tensions;

- elastic, sometimes plastic strains of the brake drum;
- fault in the geometrical trueness of the brake system and of certain elements of the wheels, defects in their position and uniaxiality.

However, all these factors can only increase the probability of the occurrence of self-closing.

Anyway, the possibility of self-closing is the consequence of the use of improperly constructed open-eye brake shoes.

Conclusions

On the basis of the above, self-closing can be eliminated in the following ways:

- by applying closed-eye brake shoes,
- by modifying the plane intersection of the open-eye brake shoes,
- by shifting the bearing angle of the brake linings on the trailing brake shoe in the direction of the brake adjusting lever,
- by using soft friction lining materials with internal or external softening and of a constant $\mu - T$ diagram.

The subject of this presentation is the study of the irregular braking phenomenon, of the selfblocking of simplex brake system of vehicle's and buses. The welded brake-shoes are connected to the fix pins with an open stitch. We calculated on the basis of mechanical and mathematical analysis the equations of forces and torsional stresses acting on the pin. On the basis of these equations we determined those conditions when the forces are acting out of contacting surfaces between the fix pin and stitch. We had proven if the coefficient of friction is bigger than 0.48 the fix pin will not hold the stitch, and the stitch will leave the pin. We had proven futhermore that the ovality of the brake drum and the unproper location of brake insert on the brake shoes will force the self blocking.

As it is known resin asbest type lining is is widely used for buses and vehicles. According to the $\mu - T$ diagram of the resin-asbest lining determined by the Cuna—Ranzi method the value of μ changes with T, and there is a slight increase with temperature.

Futhermore there is some difference between the declining and the recovery period.

The follows are the possibilites for ceasing or excluding the probability of the self shutting of the brake system:

- the using brake-shoe with a closed stitches,
- the changing of section of stitches,

— the changing the position of lining,
— the decreasing of the rigidity of brake-lining using inner or outer softeners,
— the proper installation the geomerty of the first axle and wheels and the brake-system.

References

1. Bussien: Automobil Technisches Handbuch. Technischer Verlag, Herbert Crom, Berlin 1965.
2. Lieng-Huang, L.: Andvances in Polymer Friction and Wear. V 5/B 623—647 p (1974).

Dr. Kálmán Dezső
Dr. István Emőd
A. A. Mubarak
Dr. György Lipovszky
Dr. Lajos Tóth
Dr. Ferenc Varga
} H—1521, Budapest