Self-energising electro-hydraulic brake (SEHB)

The Institute for Fluid Power Drives and Controls (IFAS) forms part of Aachen University of Technology (RWTH Aachen). This report tells about the development work it has been doing on a self-energising electro-hydraulic brake (SEHB) in the context of a project sponsored by the German National Science Foundation (DFG, Deutsche Forschungsgemeinschaft).

The literature contains numerous reports on attempts to implement concepts for electro-mechanical or electro-hydraulic add-ons to conventional air brakes. A brake whose only mode of operation is electro-hydraulic can do entirely without the production of compressed air and can thereby save on the energy needed for it.

Most of the railway brakes in use today do not incorporate self-energisation. Their behaviour is stable and predictable. The use of the self-energising effect very considerably reduces the power needed by friction brakes. If a self-energising effect is applied to unadjusted brakes, however, fluctuations in friction may have drastic effects on the deceleration torque, which, in extreme cases, may even be the cause of instability. The self-energising electro-hydraulic brake (SEHB) developed at the IFAS minimises the risk of instability by making a continuous fluid-mechatronic adjustment to the deceleration torque in combination with simple hydraulic safety mechanisms.

1 How the self-energising electro-hydraulic brake functions

The SEHB can be implemented in the form of a disc brake. It is fastened to the running gear in the same way as conventional brakes. Since it draws its energy from the braking process, it is possible to do without power connections along the length of the train.

Conventional friction brakes have the disadvantage that the contact force of the brake pads pressing against the brake disc is predetermined. There can thus be very strong variations in the braking torque as a consequence of fluctuations in the coefficient of friction, which it is very difficult to predict. With the self-energising electro-hydraulic brake, on the other hand, it is possible to adjust the actual deceleration torque without needing any additional components. The advantages are obvious. Firstly, the braking distance can be shortened by reacting sensitively to the adhesion actually available at the wheel/rail contact. Secondly, the feedback of the deceleration force permits the use of a model-based estimation of velocity.

The principle of the self-energising electro-hydraulic brake is outlined in Fig. 1. One immediately striking feature is that the braking torque is taken up by the bogie through a support cylinder. The normal force generated on the brake actuator is converted into a tangential frictional force through friction contact. The brake caliper’s moveable suspension directs the friction force onto the support cylinder. The oil inside this is compressed, and a pressure is built up. The support cylinder is connected to the brake actuator by means of a valve control, making it possible for the self-energising loop to be closed. Closing this valve has the effect of interrupting self-energisation.

2 Review of the brake concept

One consequence of self-energisation is that the build-up of the braking force is unstable. The pressure differential across the open valve increases with increasing braking force. If a hydraulic resistance is encountered, such as a regulating valve, the increasing pressure differential will result in an increased volume flow. This accelerates the build-up of the braking force, which is why it is essential to develop new types of valves for the self-energising electro-hydraulic brake in order to compensate for this effect.

A test rig was set up at the IFAS for the purpose of validating prototypes of regulating valves. Its concept includes inputs resulting from the experience with preceding projects. Attention is drawn to the following findings and aims:
3 Mechanical principle of brake-pad guidance

The brake calliper has to be suspended in such a way that it is free to move, permitting the friction force to be directed to the support cylinder. The calliper's range of movement is determined by the stroke of the support cylinder. This is decided on at the time of design. Given that braking torque is the product of the frictional force and the friction radius, it is advantageous to be able to guarantee a more or less constant friction radius. This can be achieved by guiding the calliper either through an internal connection to the wheel-set axle or through an external connection to the running gear frame.

3.1 Internal circular guidance of the brake calliper

An internal circular guidance (Fig. 2) is characterised by the fact that the brake calliper is attached to the wheel-set axle by means of a rotating bearing. The friction radius remains constant throughout the whole of the brake's working range. Split bearings are envisaged for installing the self-energising electro-hydraulic brake and they must be designed for a long service life. The disadvantages of this variant include not just the high costs for the suspension but especially the installation of the brake on the unsuspended wheel set. In this situation, both transverse and longitudinal accelerations are transferred directly to the brake. The limited space available for installation to the side of the axle-mounted brake disc must also be regarded as a critical point. This might make it essential on some bogies to install the suspension on one side. The asymmetrical force transmission, which would thus be inevitable, would cause a tiltting torque. The guidance mechanism would then have to be correspondingly massive in its design to compensate for this.

3.2 External guidance of the brake calliper

In order to get round the whole problem of axle suspension, it is possible to place the guidance mechanism for the friction length on the bogie frame. Six-piece lever drives permit precise circular guidance, but they are large components. Less space is required for the installation of four-piece lever drives. These permit a good approximation of a circular path. Figure 3 illustrates an external brake-calliper guidance attached to a running gear frame, with the brake pads being guided virtually along a circular path by means of a four-piece lever drive. The self-energising electro-hydraulic brake illustrated here is flange-mounted to the bogie, as is the case with conventional air brakes. There is adequate space available for this arrangement.

In this instance, an external system has
Two possible versions of a support cylinder with just one hydraulic chamber are presented in Fig. 4. The first of these is based on a special version of a plunger cylinder, and the second is derived from a synchronous cylinder.

The “housing-plunger” variant has two plunger rods arranged in a moveable chamber. This chamber is surrounded by a fixed housing with a guiding groove machined into it. The supporting force is transferred to the moveable chamber via two lugs. The force is supported, in turn, through the oil and the piston on the housing. The other piston is made to move as well by engaging an end stop.

What characterises the “rod-plunger” concept is that there are two moveable cylindrical pistons inside one housing. A piston rod is fed through both pistons and they are able to move along it. The cylinder barrel is fastened to the bogie, whereas the support force acts on the piston rod. One of the pistons is moved along as well in the direction of the force, whereas the second piston is blocked by its end stop. Each of the pistons can only move as far as the middle stop. This makes it possible to position the drilled hole for the oil connection in a permanent location in the middle of the support cylinder.

If the height of the piston’s ring gap is sufficient, the oil connection can be made, as an alternative, through a hole drilled in the movable piston. This makes it possible to use a shorter cylinder without reducing its stroke, because the middle stop becomes superfluous and it becomes possible to move the pistons until they are alongside one another. Essential advantages of the “rod plunger” are the direct application of the force and the simple fastening to the brake and bogie. All the components can be manufactured for little outlay. For this reason, it is this variant that is going to be further pursued in future.

6 Concluding summary and prospects

The whole of the concept presented above was arrived at through careful consideration of both functions and costs. It has been decided that for the further development of the research project supported by the German Science Foundation the principle to be used is to be that of external radial guidance by a four-piece lever drive in combination with an open hydraulic circuit. The force necessary for a parking brake is to be provided in two stages. Firstly, a spring on the brake actuator is to provide a minimum parking-brake force for an unlimited period of time, even in the absence of a connection to an external energy supply. Secondly, the installed pump is to support the parking-brake force temporarily as required. In addition to that, the intermediate-pressure reservoir can be continuously pressurised by the pump, ensuring that a constant braking force is always available. The inclusion of a pump naturally increases the costs. Since, however, only a constant pump for a low pressure level is required, a very low-cost pump is perfectly adequate for this purpose.

A detailed design of the functional prototype of the improved self-energising electro-hydraulic brake is now to be drawn up on the basis of the solution discussed here. The dynamics of the build-up of the braking force increase with increasing self-energisation. In order to counteract this effect, it is still necessary to have a 2/2-way valve with proportional characteristics free from leaks in its closed state. The volume flow through the valve could thus be adjusted to the brake’s working point. Valves of this nature are currently not available on the market, but they would be of interest in many applications with energy-efficient hydraulic systems. The iFAS itself is working on the development of valve prototypes with the properties mentioned. These are being tested on the rig referred to above in combination with the implementation of non-linear control algorithms. Once all this has been completed, the build-up of the braking force ought to behave stably over the whole working range in combination with simplified valve control and additional convenience.