Control Systems of Modular Expansion Joints
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1 Introduction / Summary

The way in which the overall movement of a modular expansion joint is distributed between the joint’s individual gaps is a very important feature of the expansion joint’s design and functioning. Various systems have been developed, each offering its own characteristics.

In principle, such control systems can be classified as elastic or rigid: Elastic systems offer a number of advantages over rigid systems:

- They can readily accommodate constraints, should the movements of any part of the joint be hindered in any way (e.g. should a gap become blocked by a stone, in which case the other gaps will compensate by taking more of the movement). As a result, constraint forces that could easily damage the joint are avoided, and the joint offers far higher resistance to fatigue.

- The elastic support of the joint’s structural elements contributes to good damping of the overall system against dynamic impact loads from traffic, increasing durability.

The only possible disadvantage of an elastic system is that gap widths across the joint can vary due to accumulating friction forces, with more movement arising at the moving side than at the fixed side of the joint. This is unlikely to be of any consequence except for joints with many gaps, for which the design can be adapted to ensure no problems – e.g. by making the control system asymmetrical or by adding gap limiting belts. Therefore, it must be concluded that elastic control systems offer significantly better performance, durability and resistance to damage than rigid systems.

Elastic control systems can be further classified as multiple crossbeam or single crossbeam, depending on the number of crossbeams, which support the lamella beams which create the joint’s driving surface, that are provided at each location along the joint where lamella beams require support. In the case of multiple crossbeam systems, each lamella beam is supported by (and rigidly connected to) its own crossbeam at each support point, while the crossbeams of single crossbeam systems support every lamella beam. Multiple crossbeam systems have several significant disadvantages compared to single crossbeam systems:

- The number of crossbeams, and therefore the number of lamella beams, is limited to approximately eight, limiting the maximum movements for which this type of joint can be designed.

- The accumulating friction forces which result in unequal gap widths are more significant because sliding occurs at two locations (at both ends of each crossbeam).

- The rigid connection itself, between lamella beam and crossbeam, very often welded, is prone to fatigue failure.
In response to these problems, mageba (although the inventor of the system) stopped using the multiple crossbeam system in the early 1980s, developing instead the single crossbeam system which it still uses today. In addition to addressing the above disadvantages of the multiple crossbeam system, the mageba single crossbeam system offers the following advantages:

- **Sharing of loading**: The location of the control system in the fields between the crossbeams provides additional support for the lamella beams. The connection together of three lamella beams by each control set shares loading among the beams, and thus reduces the deflection and rotation of individual beams.

- **Dissociation of functions**: The arrangement of the control system clearly dissociates it from the lamella beam / crossbeam connection. Thus, the stirrups which connect the lamella beam to the crossbeam are not subjected to any additional load from lamella beam movement.

- **Damping**: The locating of the control system in the fields between crossbeams contributes to improved damping of the lamella beams in all directions.

As a result of all these considerations, it can be concluded that the elastic, single crossbeam control system developed and used by mageba is technically superior and can be used with confidence in bridge structures of any type and size.
2 Overview of modular expansion joint control systems

2.1 Principles of operation modular expansion joints

The principle of operation of the modular expansion joint is based on the division of the gap between the bridge deck and the abutment into a number of smaller gaps, separated by individual beams (called “lamellas”). These individual gaps are securely sealed by elastomeric profiles which make the joint 100% watertight. Therefore, the expansion joint bridges the gap between the bridge deck and abutment, while facilitating movements due to settlement, temperature variations, traffic, and creep and shrinking deformations of the concrete structure. The expansion joint permits traffic to cross this gap comfortably and safely.

The traffic loading is transferred from the lamella beams, via supporting crossbeams, into the bridge deck and abutment.

A control system is required to spread the overall movement of the joint among its individual gaps, ensuring that no single gap will be too large for traffic to negotiate. This control system must also be capable of transferring any horizontal forces from traffic (for example, braking forces) from the lamella beams to the support structure. Depending on the design of the expansion joint, the control function is taken by different elements. Four of the most common methods will be described below, subdivided into Sections 1.2 (Constrained controlled systems) and 1.3 (Elastically controlled systems) depending on the overall approach to the design.

2.2 Rigid control systems

Rigid control systems ensure the equal distribution of total gap movements among the individual gaps between the lamellas. Should the movement of the system be hindered in any way, or should stresses arise due to fabrication tolerances or temperature differences, this type of control system is susceptible to damage. For example, if a gap is blocked by a stone or similar, the rigid control system will be damaged. All gaps have to move equally out of geometrical constraints, if one gap is blocked, something (the position of the failure is difficult to predict) has to break (see examples in Appendix A).

2.2.1 Swivel-joist control systems

Swivel-joist (or swivel-crossbeam) systems consist of lamella beams supported by crossbeam units which are placed at an angle to the joint’s axis and which rotate and slide as the bridge gap opens and closes. The lamella beams are connected to the crossbeams by swivel articulations. Due to the angle between the joist beams and lamella beams, the gaps are forcibly adjusted and are therefore always uniform. Swivel articulations are characterised to be highly rigid and are therefore only able to compensate unforeseen constraints when very high force values occur.
2.2.2 Scissor control system

Scissor constructions can be considered as totally rigid. The lamella beams in these systems are densely connected to the scissor units. This transfers the load from lamella beams to joint edge profiles and simultaneously serves to provide a uniform distribution of separation gaps. Experience shows that, due to the rigid connections of the single components, these joints are characterised being noisy and subject of high wear and tear.

Fig. 1: principle of joist arrangement for swivel expansion Joint type (Source: Patent EP0163759A1)

Fig. 2: Modular expansion joint with scissor control system
2.3 Elastic control systems

Elastic control systems use elastomeric springs which work through compression and shear forces to restore the elements of the joint to their original positions. Elastically adjustable systems respond well to constraint forces and fabrication tolerances, temperature variations between different structural elements, and deviations from planned direction of movement. Such deviation from planned direction of movement of individual lamella beams can also be easily accommodated by elastic control systems.

2.3.1 Girder grid control systems (multi-support bar expansion joints)

Under this construction, the lamellas are fixed to the supporting crossbeams, which can move relative to the supporting structures at each side of the expansion gap. The number of lamella beams is limited to approximately eight, and thus the size of the expansion is limited accordingly, since each lamella requires its own crossbeam. Gap control is achieved through springs connected one after another. On the basis of accumulating friction force and control action, which are well balanced, gap width becomes unequal. Especially negative influence occurs when each lamella is connected to its own single crossbeam, as the forces of sliding friction arise in two places. Experience shows that on the basis of rigid connections between the lamella and the crossbeam, these design units are subject to fast deterioration. Additionally the welded connection between lamella beam and the cross beam is very often subject to fatigue failures. The experience over decades showed clearly, that this fatigue failure susceptibility can’t be fully eliminated. The now often used ultrasonic impact treatment can enhance the durability of the weld but not fully eliminate the failure susceptibility.

This system-related problems are the reason why mageba stopped producing this kind of lamella joint (even if mageba was the inventor of this system) early in the beginning of the 80s.

Fig. 3: view from underneath and cross section of a modular expansion joint with girder grid control system, multi-support bar expansion joint type (Source: Tiefbaufugen, Ernst & Sohn)

2.3.2 mageba elastic control system

The mageba system consists also in an elastic system, where each lamella beam is supported by single crossbeams equally located (every max. 1.8m), where the lamella beams can slide along the crossbeams. This connection between lamella beam and crossbeam, similarly to the connection between crossbeam and its support structures, consists of
an elastically supported, pre-stressed unit (fig. 6, section A-A). Thanks to this elastic connection of the different structural elements, dynamic loads from traffic are damped and also the vibration characteristics of the expansion joint are considerably improved. The system’s elasticity and damping effect also substantially reduces the noise emission from traffic driving over the joint.

The mageba control systems are located in the fields between the crossbeams. Friction forces arise at the sliding connection of the lamellas to the crossbeams, and the control system must be able to deal with these forces. These friction forces arise from the movable joint side, the control forces are balanced, and therefore a non-uniform distribution of gap widths can occur. More detailed consideration of this process follows in section 4.

The mageba system’s elastic connectivity allows complex bridge movements to be accommodated. Movements in all directions and rotations about all three main axes are facilitated.

Fig. 4: denotation of different movement axes and different rotation
3 Explanation of the mageba elastic control system

3.1 Functions of the mageba elastic control system

The control system has the following functions:

- Changes in the width of the gap between the bridge deck and the abutment, due to temperature effects, traffic loading, creep and shrinkage are to be distributed by the control system among the expansion joint’s individual gaps.

- Horizontal loads such as braking forces are to be transferred from the lamellas to the joint edge or the support structures. This could be verified and proven by field testing (full breakage of a 40t truck out of 80km/h on the joint!)

- Torque in lamellas, due to horizontal loads, are accommodated.

3.2 Principle of operation of the mageba elastic control system

The control system of the mageba modular expansion joint is located in the fields between crossbeams, see fig. 5. The control element consists of spacing plates and control springs, which are located under the lamellas. A spacing plate is securely fixed to each lamella and connected to neighbouring lamellas via a control spring, see section C-C in fig. 6. This arrangement guarantees an equal distribution of the total gap into individual smaller gaps between the lamellas. When the expansion joint is in its central (neutral) position, the control springs are not tensioned. If the joint edge then moves, the springs are elastically deformed, giving rise to a restoring force in each spring which would tend to return the arrangement to one in which the spring is not tensioned. This distributes the overall movement between the individual gaps between lamellas. For this to function properly, the restoring force of control system should be higher than the friction force arising between lamella and crossbeam.

![Fig. 5: Longitudinal section and plan view of a mageba modular expansion joint of type LR4](image-url)
A - A Lamellas and crossbeams with relevant support components and sealing elements

B - B Crossbeam’s sliding support

D - D Lamella’s sliding support

C - C Gap width control system, showing edge beams with anchors

Fig. 6: Sections to figure 2 (Details of a mageba modular expansion joint of type LR4)
4 Advantages and disadvantages of elastic control

4.1 Blockage of a gap between lamella

In unplanned situations, such as, for example, blockage of the gap between lamellas (e.g. by a stone) damage to the joint can be prevented by an elastic control system. The blockage of a gap generates automatically the compensation by closure of the remaining gaps. The system can be returned to normal operation simply by cleaning the gap or removing the offending object. In contrast, an expansion joint with a constrained controlled system (refer Section 2.2) will suffer mechanical damage in such circumstances (see examples in Appendix A).

Fig. 7: Widths of individual gaps of a mageba modular expansion joint type LR8 (eight gaps). The graph on the left shows the gap widths when the joint is closing by 70mm from its normal position. The graph on the right shows how the joint reacts to a blockage in gap 6, by distributing the movement among the remaining gaps.

4.2 The effect of the control system’s location between the crossbeams

The location of the control system in the fields between the crossbeams creates an additional support of the lamella beams. The connection of three lamellas by each spacing plate reduces deflection and rotation or tilting of the lamella, by partially transferring the forces to the neighbouring lamellas. This results in reduced loading of the connection between lamella and crossbeam.
4.3  Dissociation of functions

The arrangement of the control system as described in section 3.2 means a function dissociation between the control system and the connection between lamella and crossbeam. Thus, the crossbeam-frames do not bear any additional load from the movement of the lamellas as controlled by the elastic control system.

4.4  Damping of the whole joint system

The elastic support of all structural elements of the joint contributes to good damping of the whole system against dynamic impact loads from traffic. Further the control system in the fields between the crossbeams results in damping of the lamella in all directions.

4.5  Spacing of transverse beams – a very critical static characteristic for large joints

The arrangement of the control system as described in section 3.2 leads to a common standard crossbeam spacing, and thus a common standard lamella beam span length, which is relevant for the static assessment and therefore for the design of the joint.

This is very critical advantage compared to big joints with a swivel joist system, because the widest spacing of transverse beams with regards to any lamella beam, and thus the greatest lamella span length, is defining for the design and this will be much more than for a joint with an elastic control system. Some manufacturers of swivel joints may use a lower span than maximum for their static designs, but this is obviously not correct and will result in underdimensioned lamella beams where the span is greater.

Fig. 9:  Comparison lamella beam spans for 22-gap joints with different crossbeam arrangements
Fig. 10: Plan view of 22-gap joint with mageba elastic control system (Ulsan, Korea)

Fig. 11: Plan view of joint with swivel design option (Source: Patent US2003196400A1)

4.6 Uneven visual appearance

A small disadvantage of the elastic control system is that the spacing of the lamella beams can temporarily appear uneven, due to partially unequal gap widths. More detailed consideration of this follows in section 5.
5 Explanation and consequences of “unequal gap width”

5.1 Explanation of reasons

The unequal gap widths in the mageba system result from in the elastic control system. In a neutral position the control springs are unloaded and relaxed. If a movement occurs at the joint edge, the first control springs are activated, distorted and stimulate a restoring force for the first lamella. Because of the pre-stressed, sliding support of the lamellas on the crossbeams, friction forces occur. Due to these friction forces, the restoring forces for the gap control between the lamellas are slightly reduced. This effect on gap opening and closing causes insignificant width difference between the individual gaps. Upon opening, the gaps in the movable side of the expansion joint are a little wider, and upon closing a little narrower. Therefore, statistically viewed, the average gap width of each gap is the same and thus stress on the joint, which is relevant for the durability of the joint, is equal for all lamella beams.

It is possible to describe this effect mathematically using the following method:

\[
\begin{align*}
S_0 & \quad \text{Initial width of an individual gap} \\
W & \quad \text{Total movement of joint edge} \\
S_{Zwang} & \quad \text{Theoretical gap width by constrained control system} \\
n & \quad \text{Number of sealing profiles in the expansion joint} \\
i & \quad \text{Individual gap} \\
c & \quad \text{Spring constant of control springs} \\
\mu & \quad \text{Friction factor between lamella and crossbeam} \\
V & \quad \text{Pre-stressing between lamella and crossbeam}
\end{align*}
\]

For the example calculation, an expansion joint with eight gaps has been chosen. Initially a neutral position equal to 40mm/gap was established and a joint opening of 320mm and closing of 80mm was considered.

Sliding resistance of each lamella beam results: \( R = \mu \times V = 0,03 \times 8 = 0,24 \text{kN} \).

Theoretical gap width at constrained gap control results: \( S_{Zwang} = S_0 + \frac{W}{n} = 40 + \frac{320}{8} = 80 \text{mm} \).

Individual gap widths in the mageba system can be calculated by using the following formula:

\[
S_i = \frac{W \cdot c + \frac{n+1-(2 \cdot i)}{2} \cdot R}{c} + S_0
\]

The unequal gap width arising in the mageba control system by opening of a joint from neutral to maximum position, are shown in table 1. Only small differences in gap width are evident.

If the system is closed from neutral position at an average of 10mm for each individual gap, the resulting gap widths are shown in table 2. At the further joint closing, individual gaps will be closed, however, this has been considered in the calculations and joint design and does not result in damage to the joint or structure.
5.2 Consequences

The fact that deviations in the individual gap widths on modular expansion joints acc. to mageba’s standard control system can occur, has the following consequences:
5.2.1 Optic / Appearance

The only disadvantage is the optical non-uniformity of the system caused by eventual light differences in the gap opening. The latter, however, is not noticed by the bridge passers during normal passing of the expansion joint.

5.2.2 Dynamic

By considering the “Eigenfrequencies” of the expansion joint, eventual unequal gap widths contribute even to an amelioration of the dynamic behaviour of the expansion joint, as in the case of equal individual gap width, the danger of brace/swinging of the system is highest, due to the uniform stimulation with the “Eigenfrequency”.

**Fig. 14: Calculation of the “Eigenfrequencies”**
5.2.3 Static

From the point of static analysis, the unequal gap widths are unproblematic. The calculation and design of mageba modular expansion joints is based on the consideration of the extreme cases such as the maximum gap opening.

Fig. 15: Static calculation of a modular expansion joint with fully open gap widths
5.2.4 Fatigue strength

Considering the case of fatigue (material), the static calculations are not carried out on a system with totally opened gap widths. As the total gap opening of a structure is distributed slightly unequally among the individual expansion joint gaps, with some gaps being greater than the theoretical values, a more unfavourable level of fatigue might be expected. In reality, the gap openings of all single gaps are statistically equal because the gaps, which open more during the opening of the joint, also close more during the closing of the total joint. Therefore, the resulting strain of the lamellas with the slightly higher movement is equal to that of those, which move less.

Fig. 16: Fatigue limit state calculation
5.3 Ways of addressing unequal gap widths

Varying gap widths across an elastically-controlled joint is unlikely to be of any consequence except for joints with many gaps, but the design of any joint can be adapted if desired to ensure no problems.

For example:

- the control system can be made asymmetrical with the addition of additional control spring sets at the moving side of the joint to encourage less movement at this side and more at the other;
- gap-limiting belts can be added, connecting the lamella beams together and preventing any individual gaps from exceeding a desired maximum value; and
- specially developed UHMWPE-compound sliding materials (e.g. Robo®Slide), which are characterised by low friction and low abrasion and therefore offering increased durability, can be used instead of PTFE at the joint’s sliding interfaces.

As a result of such measures, the phenomenon of unequal gap width can be effectively addressed, ensuring that it is never a disadvantage of any sort.

6 Conclusions

Summarising the above, it can be confirmed that the eventual deviations from a theoretical value of individual gap opening between two lamellas in a mageba modular expansion joint system can not be considered as a disadvantage. Contrariwise, the flexible elastic control of the mageba system is a high advantage. Thanks to the dissociation of the functions in the transfer of loading, respectively the connection between the lamella and crossbeam, and the widths control by the location of the elastic control systems between the crossbeams, the stress on separate components can be considerably reduced. In unforeseen situations, such as in the blockade of an individual gap, the mageba system shows its benefits, as it - due to the flexible accommodation - results merely in a reduction of the remaining gap widths and does not damage the expansion joint or the bridge construction.

On very large modular expansion joints with a high number of lamella beams the friction is increased to higher values, thus increasing the possible deviation of the gap width from the theoretical values. For the application of large modular expansion joints with mageba’s elastic system, several technical features and solutions have already been developed and successfully installed. To reduce the individual gap width differences to a minimum – mageba equips their large modular expansion joints with an asymmetrical control system. In an asymmetrical control system, the control forces are adapted according to the occurring friction forces. Further for large modular expansion joints mageba adds a mechanical gap control, by gap control bands, guaranteeing that a maximum gap width will not be exceeded (normally 80mm/gap). Finally a new sliding material called Robo®Slide for mageba’s sliding components (bearings & springs) on large modular expansion joints is characterised by low friction, low abrasion and therefore increased durability, additionally contributes positively to the reduction of the uneven gap width between the lamellas.

These technical upgrades have been successfully applied for many years and have proven its functionality in practice. The following examples of mageba modular expansion joints, show that in practice the phenomenon of unequal gap width is unproblematic and furthermore, that the principle of elastic control offers serious advantages.
Fig. 17: Example: 2nd Nanjing Bridge: mageba modular expansion joints type LR20, installed 2001

Reference Letter

南京长江第二大桥使用了由瑞士玛格巴公司生产的LR20-A80（设计伸缩量1600mm）模块化桥梁伸缩装置。该装置自2001年3月26日通车以来使用至今，伸缩自如，伸缩间隙均匀，密封性功能好，车辆进行舒适，满足桥梁的伸缩需求。

LR20-A80（设计伸缩量1600mm）模块化扩展接缝由Mageba SA在NanJing Yangtze River No.2 Bridge安装。自2001年3月26日开通以来，它们一直在满足桥梁的完美移动要求，相同的间隙，良好的密封功能和舒适的车辆通过。

该公司在中国的全资子公司-Mageba (Shanghai) Bridge Products Co., Ltd.在中国，已经定期进行现场服务，并提供建议。售后服务及时。

Mageba Group将继续提供最好的产品和完善的售后服务给中国客户，为中国的公路桥梁建设做出贡献。
We hope Mageba Group will continue to provide the best products and perfect after-sales service to the Chinese clients so as to make further contributions to the construction of China’s roads and bridges.

南京长江第二大桥有限责任公司
No 2 Nanjing Yangtze River Bridge Co., Ltd.
September 2009
Runyang Yangtze River Highway Bridge Project is the key project in Jiangsu Province, P.R.C. For the construction of this bridge, through bidding procedure, we chosen expansion joints LR27 (65m movement capacity 2160mm), LR10 (65m movement capacity 800mm) for main bridge, which was supplied by China Road and Bridge (Group) Xinjin Road Construction Machinery Factory and Produced by Mageba SA. For bridge viaduct, about 1238.92m joints (D80, D160, D240, D320) have been supplied by Xinjin and Mageba (main components have been produced by Mageba). All of these expansion joints are excellent in quality, reliable in performance and rational in design. Thanks to the skilled and diligent installation team, who can carry out the installation work according to the regulations, the construction task has been accomplished with high quality in time.

(for bearings, not necessary)

Jiangsu Province Yangtze River Highway Bridge Commanding

Department (stamp)

February 5th, 2005
To whom it may concern,

Mageba Modular Expansion Joints
Tsing Ma Bridge, Hong Kong

The Highways Department of the Hong Kong SAR Government hereby gives
testimony to the supply, installation and performance of the Mageba modular expansion joints
at the Tsing Ma Bridge in Hong Kong. The bridge, which forms part of the Lantau Link and
provides a strategic road network connecting to the Hong Kong International Airport at Chek
Lap Kok, is currently the world’s longest suspension bridge carrying both vehicular and
railway traffic.

The Mageba expansion joints have been in operation since May 1997 and have
provided satisfactory performance since then. With the exception of replacement of some
wearing parts during our routine maintenance, they displayed no evidence of major defects and
served their intended purpose in full.

The expansion joints installed on the bridge by Mageba are as follows:

- Tsing Yi Abluation: 4 x modular joint type LR25 (25 gaps) – total 35.90m
- Tsing Yi Slip Roads: 2 x modular joint type LR25 (25 gaps) – total 23.00m

The Mageba’s technical competence and support including after sale service are
considered satisfactory and their staff has always been helpful and cooperative.

Yours faithfully,

(Y.C. K Wong)
for Chief Highway Engineer

Bridges and Structures
Highways Department

Fig. 19: Example: Tsing Ma Bridge: mageba modular expansion joints type LR25, installed 1996
Appendix A

Examples of failures occurred in praxis at expansion joints with a constrained controlled system:

Fig. 20: Unequal gaps of an inelastic controlled expansion joint due to external constrains
Fig. 21: Damage of bearing/steering unit at non-elastic expansion joint type
Fig. 22: Too big and also unbuttoned first gap at alternative expansion joint type
Fig. 23: Unequal gaps at competitor’s expansion joint type
Fig. 24: Repaired fracture of the welded connection between centerbeam and the cross beam at all 4 support bars of an alternative lamella joint type