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New Design Features and Guidelines for Hydraulic Cylinders

by

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1. Introduction

During the 5th Biennial Symposium the proof of new technology such as the ceramic piston rod coating Ceramax and the to Ceramax related Ceramax Integrated Measuring System (CIMS) was presented. This technology combined with proven in practice construction details and experience with regulations results into application based standards or modules for Hydraulic Cylinders for bridges.

2. Projects

The following 2 projects shows the specially for the application designed cylinders, with each their specific characteristics:

Brickell Avenue, Miami, FL

The Brickell Avenue bridge (fig. 1) is a newly built 4 leave bascule bridge over the River Miami, operated by 4 hydraulic cylinders per leave. The design of the cylinders are based on the earlier mentioned modules, involving Ceramax rod coating and the widely applied and proven standard seal and bearing design.

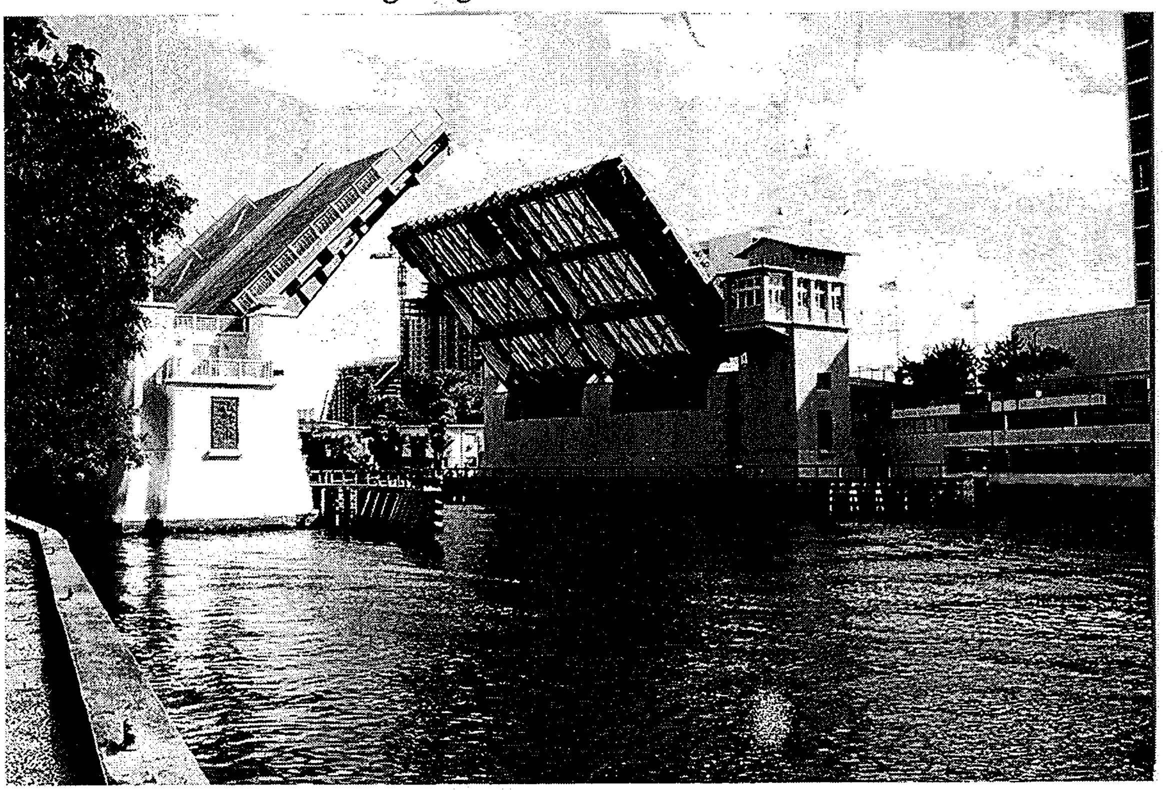

fig. 1, Brickell Avenue Bridge

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Erasmus Bridge, Rotterdam, the Netherlands

The Erasmus Bridge is a 410 meter long a-symmetric suspension bridge (fig. 2), over the main waterway, River Maas, in Rotterdam harbor, combined with a single leave bascule bridge, 33.13 m wide, 57.8 m long. The 4 hydraulic cylinders, bore 600 mm and stroke 6940 mm, are specially designed to meet the very strict requirements of the Rotterdam City Council and the manufacturer of the operating machinery. To measure the leave position, 2 cylinders are equipped with the CIMS position indicator.

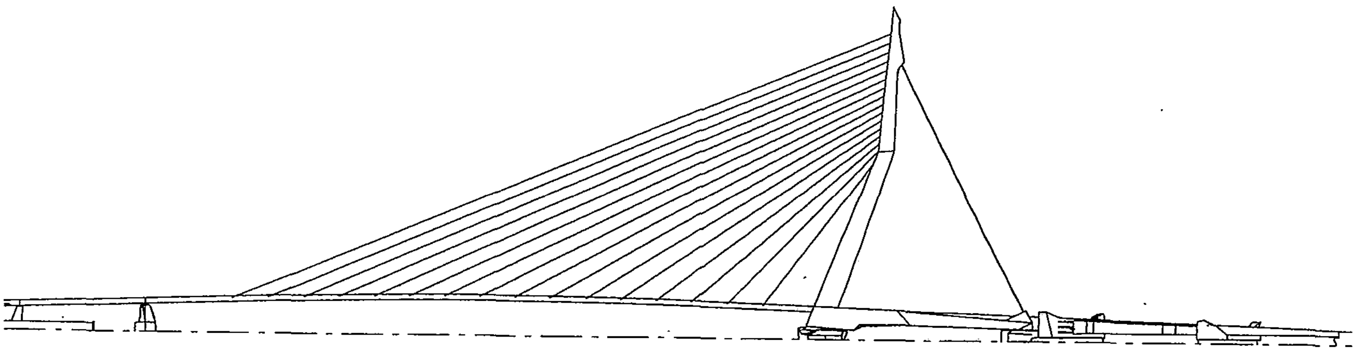

fig. 2, Erasmus Bridge

3. Proven Technology

Both the above mentioned projects clearly demonstrates the possibilities with modern technology. Past experience is the basis for the typical application based standard cylinder configuration for bridges complete with upper and lower mounting brackets as shown in fig. 3.

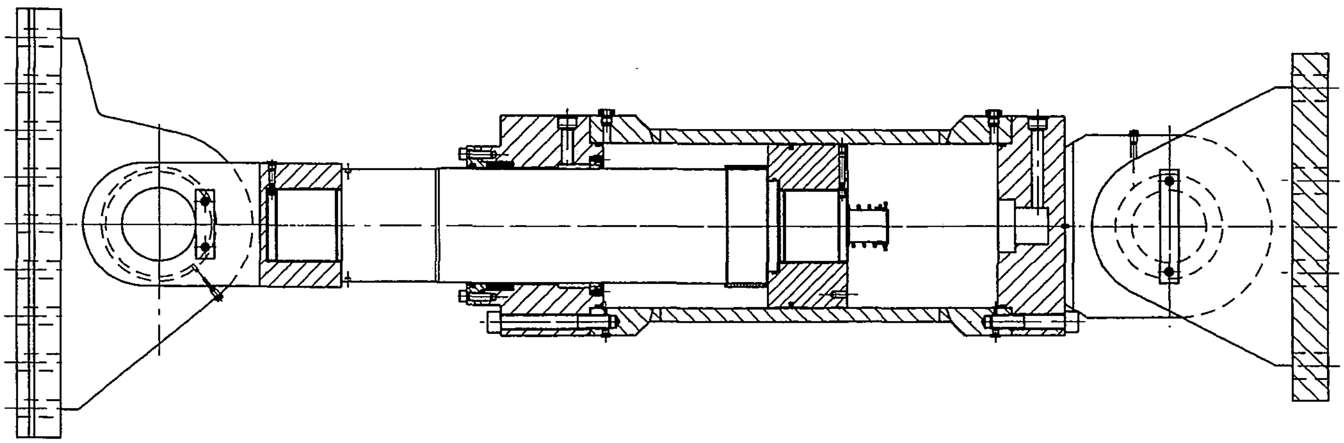

fig. 3, Typical bridge cylinder

An update in technology

Continuous search for improvements demands for innovations. The vulnerable parts of cylinders are clearly the seals and the piston rod.

The classic sealing configurations uses chevron or multi-lip V packings. These Chevron seals are available only in NBR or in Viton material and the commercial availability is restricted to standard dimensions only. Higher demands on life time (reduction of friction), speed other hydraulic mediums requires a development in seal design. Fundamental research based on mathematical model of both the rod surface and the seal parameters will direct the design of new and modern seal shapes and compounds. This development goes in the direction of low friction seals like step seals offering a large variety in seal compounds, pressure range etc.

To reach the optimum corrosion resistance the piston rod has to be coated with the ceramic piston rod coating Ceramax. This is in the mean time a world-wide accepted standard. Salt spray testing proved the high corrosion resistance of the Ceramax. As Rexroth opted for a clear improvement of the corrosion resistance compared to the known piston rod coatings, such as chromium plating, the goal was set for a corrosion resistance of at least 1000 hours salt spray testing. 1000 hours salt spray testing according ASTM G85 or DIN 50021 ESS is regarded as a bench mark for the highest corrosion protection level.

Rexroth Hydraudyne in the Netherlands have developed the layer and production technology for Ceramax. To obtain the homogenous, uninterrupted and non-conducting layer with the required quality (hardness and roughness), the coating process is controlled by a computer operation machine. The in house Ceramax Coating Center is the proven source to secure Ceramax cylinders with high and consistent quality.

Using the non-conduction properties of the Ceramax coating the position indicator CIMS (Ceramax Integrated Measuring System) is developed. CIMS has two fundamental advantages for Civil Engineering applications: it is independent of the stroke length, extremely robust by virtue of the advanced ceramic coating technology used on the piston rods and it sensor located in the pressure less area in the cylinder, were it is not subject to influence from the outside. If required, two or three sensors can be placed in the packing flange to create redundancy.

fig. 4, CIMS mark II

CIMS consists of 3 main parts, the serrated Ceramax rods, the sensor and the electronics. With CIMS mark I, the separate electronics box had to be mounted within 3 meters to the sensor. With the second generation CIMS (Mark II) extensive miniaturization has been achieved. With this development it is made possible to combine the sensor and a minimum of electronics in one watertight housing, see fig. 4. The incremental output signal (RS422 format) can lead over long distances. The third generation CIMS is a absolute measuring system, which solves the undesirable loss of position after a power interruption. In that case a power back-up is no longer required. CIMS is compact and easily accessible for maintenance purposes.

4. Application based construction details

Buckling

The lay-out and dimensions of a hydraulic cylinder is usually determined by maximum force and available pressure only. Mounting styles have a considerable impact on the stability of the total cylinder. For instance, a clevis to clevis mounting has a long center to center length compared to a front positioned trunnion and clevis. This difference in built-in length determines the allowable buckling load. Restricting the buckling length results in a reduced rod diameter and therefor costs, see fig. 5.

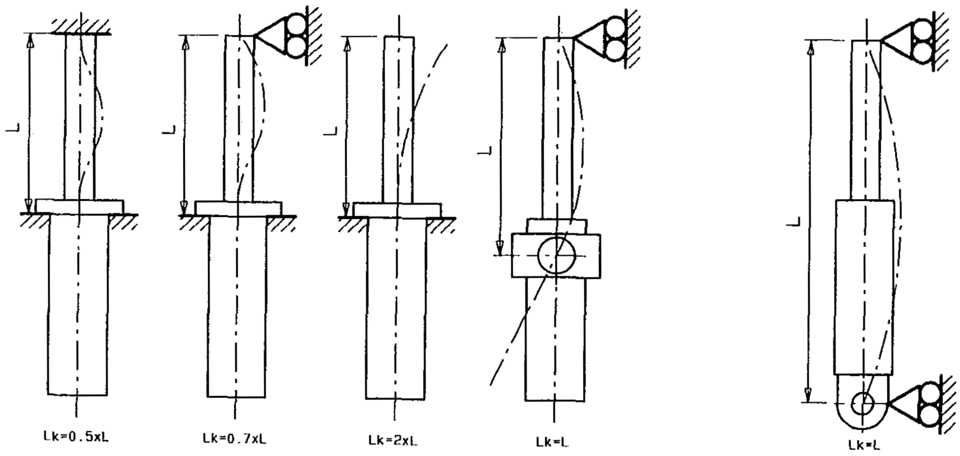

fig. 5, Buckling situations

Also, if the stroke length of a horizontally mounted cylinder becomes to long in relation to the diameter, the own weight of the cylinder will have a influence on the bending forces in the rod, the bearing load and the buckling stability. For each application and situation these parameters have to be regarded.

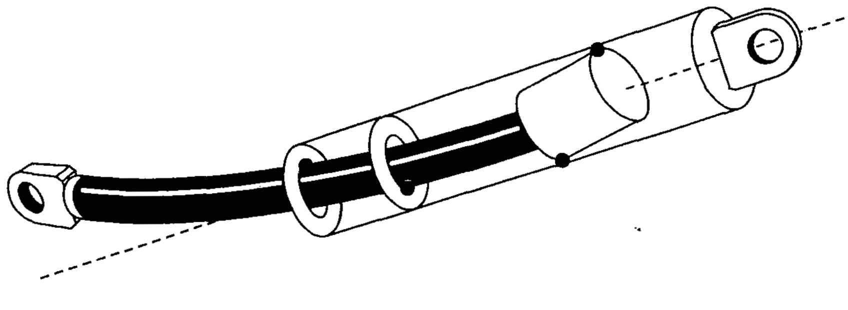

fig. 6, Horizontally mounted cylinders

Cardanic Ring

As mentioned earlier, a trunnion mounting reduces the buckling length. A trunnion has only one degree of freedom. If also alignment in the perpendicular axis of the trunnion is required, a gimbal mounting is the solution. This gimbal mounting uses a cardanic ring construction as per fig. 7. The ring is a one piece flame cutted part connected to the female trunnion on the cylinder shell with separate pins. This allows to disassemble the cardanic ring and replacing the wear parts in this construction without extensive re-machining of the cylinder. This cardanic ring construction is very compact, resulting in a minimal distance between the pillow blocks. With this reduced distance the bending in the ring is lower, thus the ring can de designed lighter.

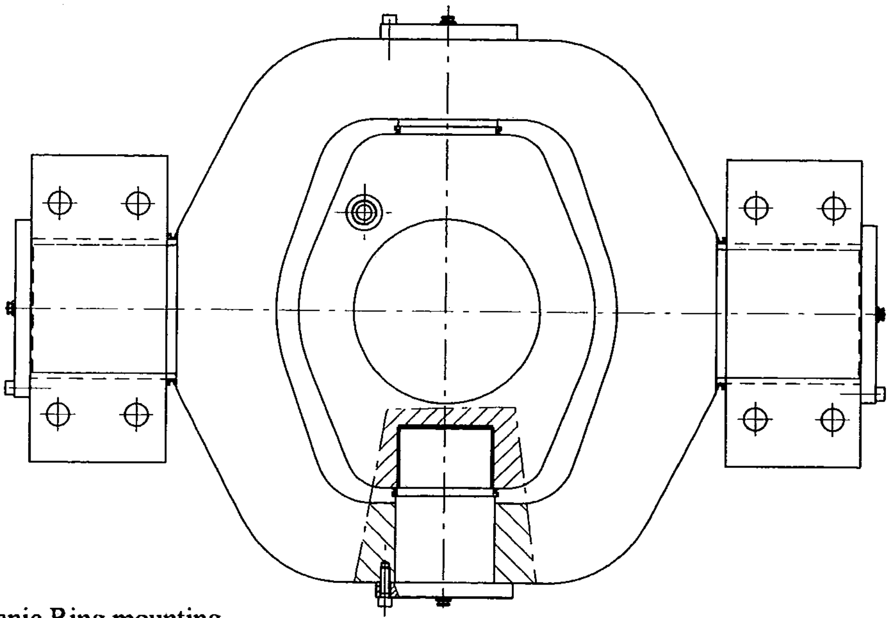

fig. 7, Cardanic Ring mounting

Cushioning

The objective of cushioning is to reduce the speed of a moving mass, whose center of gravity lies on the cylinder axis, to a level at which neither the cylinder nor the bridge can be damaged. The self-regulating end position cushioning, as shown in fig. 8 decelerates the cylinder and load to a acceptable metal to metal contact speed (< 0.1 m/sec). The effective cushioning length adjusts automatically to the current requirements. In order to make the cushioning effective it must be preset based on data such as speed, moving weight, temperature etc.

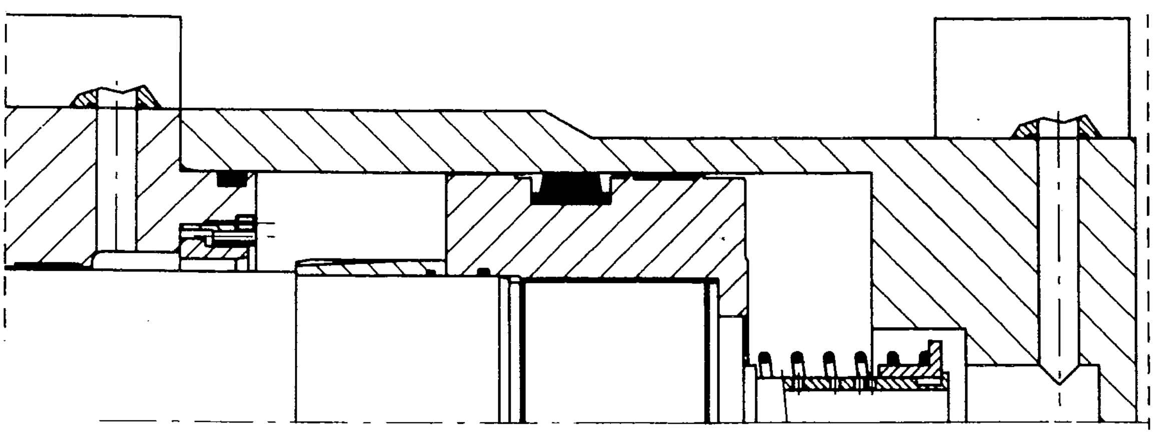

fig. 8, Self regulating cushioning with integrated check valve

5. Guidelines

Governmental organizations such as ASTM, AASHTO, DIN and ASME are there to guide the designers with minimum requirements and guard the users as much as possible for repeating problems. For an optimal result and cost effectiveness these guidelines have to be interpreted and used correctly. Hidden extra safety factors must be avoided. As an example for shell calculations, the ASME Boiler and Pressure Vessel Code calculates the wall thicknesses based on the tensile strength of the material. A much more to reality is to calculate to the yield of the material. The ratio yield/tensile is for every material different. With modern high strength materials the yield point is closer to the tensile strength, resulting in lighter constructions with maintaining the same safety factors.

Example

design pressure P	21 N/mm²
Bore	360 mm
Shell material MW450N	
Yield	420 N/mm²
Tensile	570 N/mm²

ASME BPVC

The ASME wall thickness calculation is based on a safety factor of 4 to the tensile.

Wall thickness

$$t = \frac{P * \frac{bore}{2}}{\frac{tensile}{safety\ factor} * E - 0.6 * P} + C$$

$$t = \frac{21 * \frac{360}{2}}{\frac{570}{4} * 1 - 0.6 * 21} + 1 = 30.1\ mm$$

Min. outside diameter $360 + 2 * 30.1 = 420.1\ mm$

DIN Standards

The DIN standard requires a safety factor of 2.5 to the yield.

Min. outside diameter $$OD = ID * \sqrt{\frac{\frac{yield}{safety\ factor}}{\frac{yield}{safety\ factor} - \sqrt{3} * P}}$$

$$OD = 360 * \sqrt{\frac{\frac{420}{2.5}}{\frac{420}{2.5} - \sqrt{3} * 21}} = 406.7\ mm$$

This shows that an in depth calculation philosophy can result is a optimalization in weight and costs with maintaining a high standard safety. The applied safety factors can even be optimized by performing Finite Element calculations.

Conclusion

The combination of experience, innovation and standardization offers safe, fit for use and cost effective products.

Boxtel, August 1, 1996