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"Safety in Hydraulic Cylinder Lifting Systems"

by Rene van de Ven
Rexroth Hydraudyne ABS Hydro Cylinders

Safety in Hydraulic Cylinder Lifting Systems

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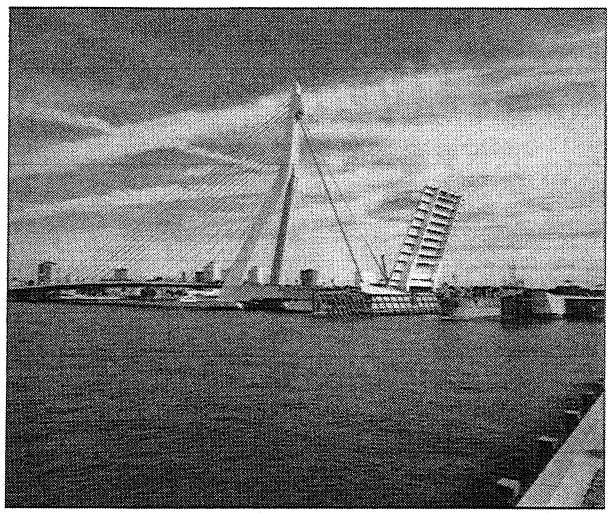


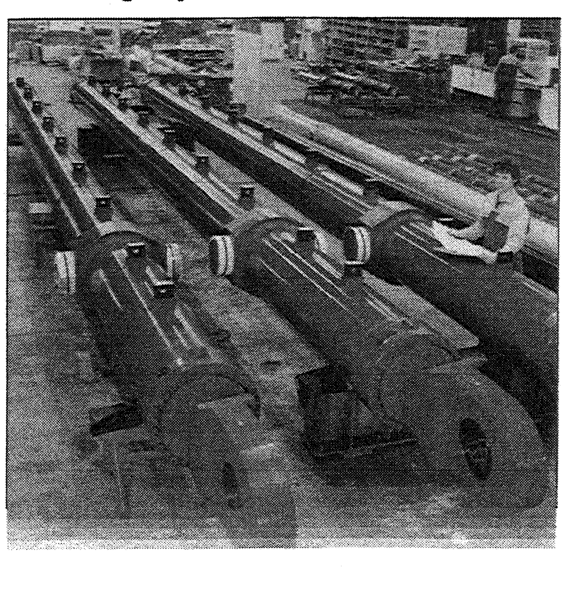
Introduction:
Rexroth Hydraudyne from the Netherlands is the Center of Competence for the design and supply for application based cylinders. In close cooperation with OEM's, Consultants and End-users application demands a cylinder concept is developed to meet the specific application demands. After the concept has proved its purpose in the application, the design is qualified as ABS (Application Based Standard). Over the last decades numerous movable bridges around the world have been equipped with ABS bridge cylinders. In close cooperation with Rexroth Corporation, Bethlehem, PA. and the Rexroth Center of Competence for civil engineering in Lohr, Germany, Rexroth supplies turn key drive systems to the American market.

ABS Application Based Standard
The ABS cylinder concept is based on three main pillars with basic reference to integrated system technology and unambiguous demarcation of the drive system and the mechanical construction. These main pillars cover:

- Influential surrounding factors;
- Functionality of the linear motor within the hydraulic drive system;
- Requirements of the cylinders as mechanical construction element.

As a basis for the design of ABS cylinders the DIN 19704 is used. The specific requirements from the DIN for cylinder design are explained later.

ABS Bridge Cylinders



If we analyze the requirements for these type of cylinders related to the pillars on which the ABS concept is based we find the following:

- Influential surrounding factors;
  Bridges are located mostly in coastal or industrialized areas. This implies that the cylinders are subjected to an aggressive or salty environment. The exposure to possible air pollution (Acid rain) or a salt-water environment demands for high corrosive resistant design solutions.
- Functionality of the linear motor within the hydraulic drive system;
  Typically the bridge leafs are driven by a set of two or four cylinders. It should be verified that the cylinders have the capacity to lift and/or hold the bridge in dynamic as well as static load situations. The position indicator systems play a key role in the safe and adequate control of the bridge drive.
- Requirements of the cylinders as mechanical construction element of the total;
  As per DIN 19704 the hydraulic steel structures in civil engineering should be designed for a lifetime of 70 years. For the drive system an expected lifetime of 35 years is required. With dynamic loaded steels structures exceeding a movement rate of 10,000 in 35 years the design should be based on an infinite lifetime. As bridges fall within this category the basis for deign of hydraulic cylinders in this application is an infinite lifetime.

Environmental Conditions vs. Corrosion Protection:

Piston rods:

The weakest and vulnerable element in hydraulic cylinders was traditionally the piston rod. Since the introduction of the Ceramax coating in 1989 this belongs to the past. Since the market introduction "Classic" Ceramax is recognized as a trend setting superior piston rod coating for general applications in corrosive and abrasive environments with proven track record. Ceramax is an in-house Rexroth Hydraudyne development. Well over 10.000 cylinders are delivered with Ceramax rod coating.

1. New spraying technology

In 1998 the possibility was created to develop and apply engineered coatings for protection (corrosion) against extreme external influences based on new spraying technology as an addition to the "Classic" Ceramax.

Further developments with this new spraying technology offers, with engineered coatings, total protection against extreme chemical attack such as exposure to 13.5% HCL in combination with 1.5% HF.

This new spraying process is based on the following. The "classic" Ceramax is applied using a plasma spraying process. This plasma process is spraying the ceramic material with very high temperatures (approx. 30.000 °C) and relatively low velocity (approx. 200 m/s). Because of this high temperature only ceramic material is suitable because it will not burn or oxidize.

With the new technology the layer is sprayed using a jet (with oxygen and fuel) with relative low temperatures (approx. 2.500 °C) but with a very high velocity (approx. 2.000 m/s). With this spraying process it is possible to compose an engineered layer to a specific task using carbides (for hardness) in a metallic matrix.

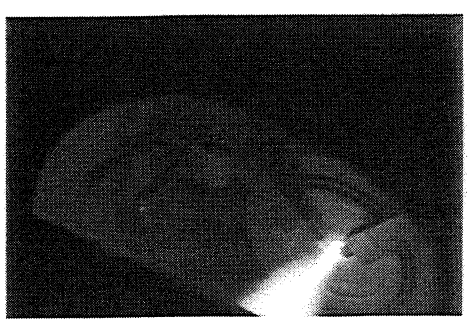


fig. 2 New spraying technology

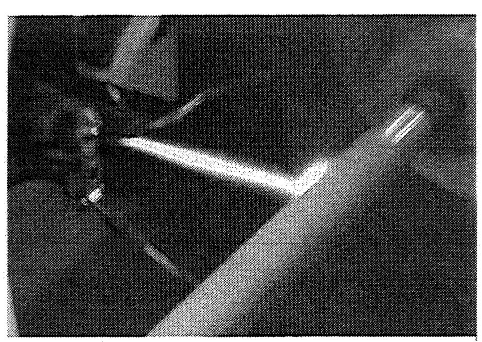


fig. 1 Plasma spraying

2. Qualification tests of new spraying technology

In line with our ISO 9001 procedures for a controlled production all coatings are qualified. The following qualification tests are performed:

- bending test
- salt spray test
- scratch and wear test
- seal test
- chemical exposure test

The tests and results as mentioned below is also applicable on the rod coating as developed for bridge cylinders.

2.1. Bending test

Piston rods of hydraulic cylinders are always exposed to bending. The first step in verifying the suitability of the rod coating for hydraulic cylinders is the bending test. For this test a piston rod is bent using a hydraulic press. The rod supported at both ends with a load in the middle (fig. 3). The rod is bent 1000 times to the yield of the base material, simulating a cyclic loading. The tested rod is checked for cracks using a dye penetrant NDT test (fig. 4). If no cracks or other imperfections are visual, a test sample is taken out of the rod from the middle and the underside (pulling side) of the rod for microscopic tests and further tests such as salt spray testing.

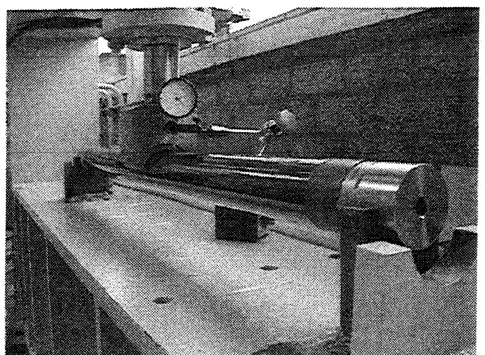


fig. 3 Test Chamber

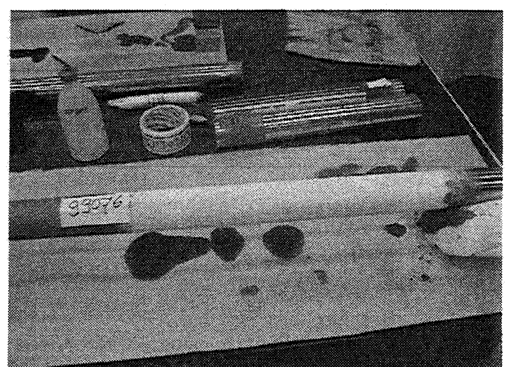


fig. 4 Sealed Test Rod

2.2. Salt spray test

The salt spray test is according ASTM G 85 and DIN 50021. After being bent the samples are submerged in a solution of sodium chloride with a concentration of 50 ± 5 g per liter, a pH of 3.1 – 3.3 at 23 ± 2 °C for a period of 1000 hours. Testing is performed at the Mannesmann Research Center in Duisburg, Germany.

Results: no findings of corrosion

2.3. Scratch and wear test

The head and packing flange of the test cylinder is modified with a chamber in which abrasive particles with or without corrosive fluids can be brought into contact with the rod coating.

Tests were performed with the following materials not being pre-stressed as well as pre-stressed with a total stroke of over 200 km:

- Silver sand with 3.5% salt water solution
- SiC shot blast grit F120 with 3.5% salt water solution
- Al_2O_3 shot blast grit F22 with 3.5% salt water solution

Conclusion: Although the rod showed longitudinal scratches no leakage or excessive seal wear was observed.

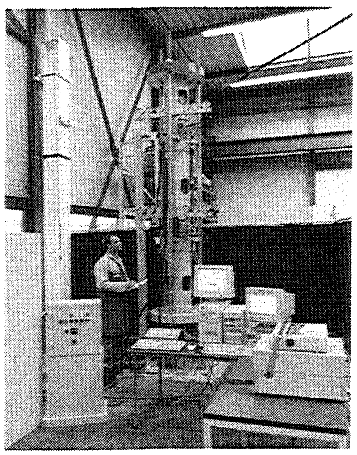
2.4 Seal test

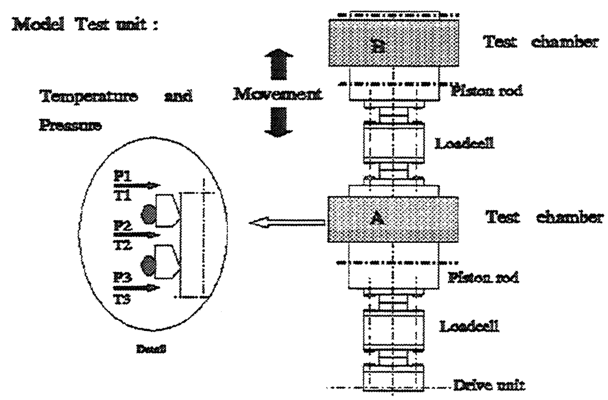
The seal test on the newly developed rod coating is extensively tested using a special test rig. This test rig offers the possibility to test under several conditions (pressure, temperature etc.) and simultaneously different seal configurations in 2 test chambers.

Over 10 different seal combinations with the newly developed coating were tested with a total stroke length over 350 km.

Conclusion: No leakage or excessive seal wear was observed

2.4. Chemical exposure test





Four samples were submitted to a independent laboratory Schielab B.V. for testing.

After protecting the ends of the samples with a sealing material and degreasing the coating, the samples were exposed to a solution of 13.5% HCL + 1.5% HF in water at a temperature of 27 °C for a duration of 100 hours. One sample was kept as reference.

After exposure the samples were visually examined and the surface roughness of all samples was determined. A section of each sample (including the reference sample) was taken and prepared for microscopic examination of the coating and the interfaces. The surface hardness of the coatings of all samples was measured.

Visual observation

Before exposure all samples had a shiny silvery metallic appearance. After exposure all samples had a dull appearance. However, no difference (with the reference sample) in appearance was observed after cleaning.

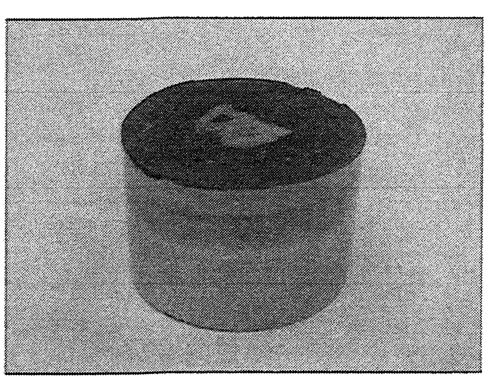


fig. 5 Exposed sample

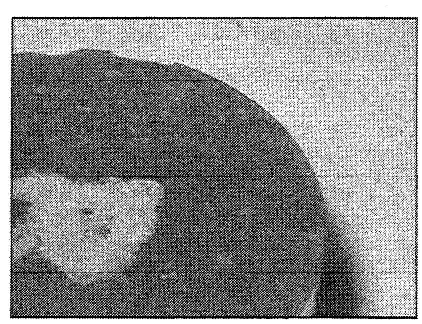


fig. 4 Exposed sample detail

Surface roughness measurements
The surface roughness was determined using a Mitutoyo Surftest 201. Three separate measurements were taken in longitudinal directions of the bars.

Measured roughness Ra 0.05 - 0.06 μ before and after exposure

Conclusion: No degradation in roughness as a result of exposure to 13.5% HCL in combination with 1.5% HF

Microscopic examination
The observations were made during microscopic examination from samples taken from the reference rod and the exposed rods.

Conclusion: No significant degradation of the layer as a result of exposure to 13.5% HCL in combination with 1.5% HF for a duration of 100 hours.

Surface hardness
The Vickers micro hardness measurements on the coating were performed on the cross-sections with a load of 19.6 N (Hv 0.2).

Measured hardness 593 – 618 Hv with an average of 601 Hv before and after exposure

Conclusion: No degradation in hardness of the layer as a result of exposure to 13.5% HCL in combination with 1.5% HF

3. Ceramax Engineered Caoting production facilities

After more than 10 years of research and development an in-house production was started in 1989 with the first coating center (fig. 10). The second coating center is operational since early 1999 (fig 11). Being a part of the Quality System the production plant is ISO 9001 certified.

4. Specifications for this specific layer

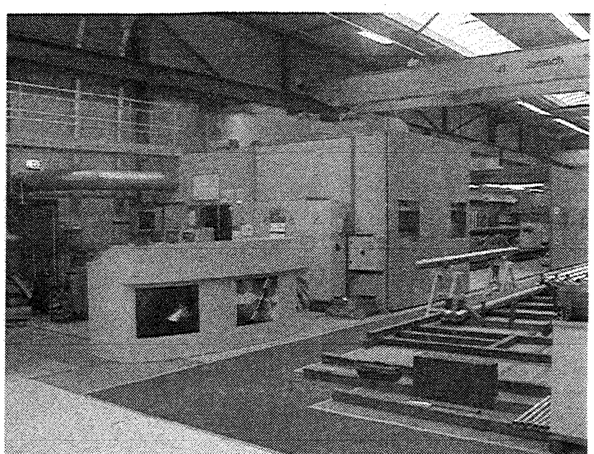


fig. 10 Coating center 1

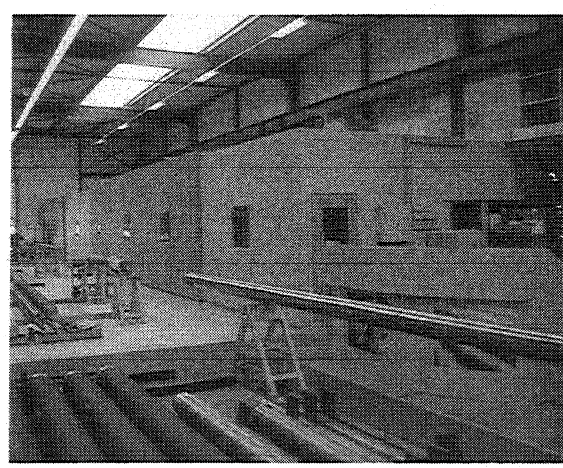


fig. 11 Coating center 2

Hardness	600 – 750 Hv
Surface roughness	Ra 0.05 – 0.15 μ
Layer thickness	> 150 micron

5. Conclusion

The piston rod coating as tested and specified above offers an ultimate protection of piston rods in aggressive salty environments.

Exterior of the cylinder:
Epoxy based coatings have proven to give the best corrosion protection in this application. Basically the choice of painting system will be universal for the bridge steel structure and the hydraulic cylinder. The optimum system is the TCP based coating. As this coating is,however, only available in restricted colors often a compromise is made on architectural considerations.

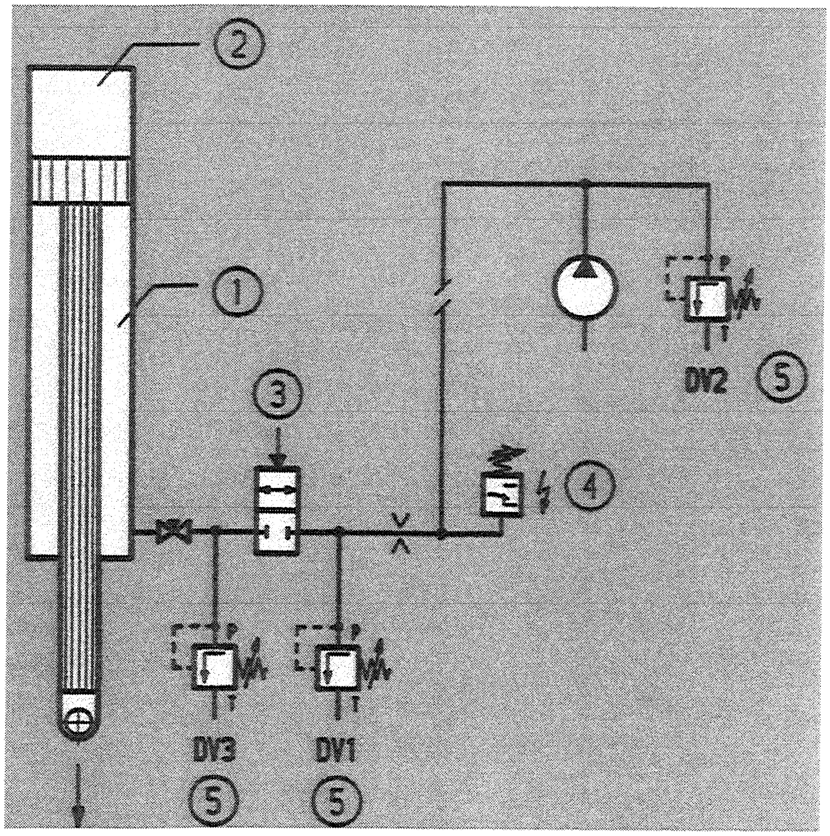
Critical corrosion sensitive areas.
Where the piston rod emerges from the cylinder normally a sealing flange is used with an integrated wiper ring. As moisture may collect in the area behind the wiper this element has to be made either out of stainless steel or chemically nickel-plated carbon steel. This will prevent rust building, which might, if occurring in excessive proportions, damage the piston rod.
The bearings used at the hinge point of the cylinders should be protected by watertight sealing systems encapsulated in stainless steel or chemically nickel-plated carbon steel flanges. The best solution can be found by using a double sealing system with an intermediate grease chamfer. This will allow penetrated moisture to be removed by refreshing the grease in the grease chamfer.
Pins to assemble the cylinders to its counter element should generally be made out of stainless steel with a minimum of 16% chromium. Inadequate seal systems may result in corrosion of the bearings increasing the bending moments in the cylinder and the cylinder support structure. The high friction and possible consequential vibrations will reduce the lifetime of the cylinders.

Hydraulic system:
The system should be designed in such way that maximum water content of 30-80 ppm in the oil is not exceeded. In this way the integrity of the interior of the cylinder will be maintained. Water contents exceeding this level may cause internal corrosion and consequential leakage of dynamic seals. Special precautions have to be taken during transportation and possible storage of the cylinders. It is advised to fill the cylinders to a level of 80% with oil. In addition an additive should be added which will vaporize and protect the area above the oil level. A good example of such an additive is the Shell VSI concentrate which in most cases can be mixed with the system oil when the cylinders are put into service.

The Cylinder as a linear motor:
The cylinder has basically the function to transfer the energy induced to the cylinder by means of the oil pressure into a linear movement. The characteristic of the cylinder as a linear motor is determined by numerous factors:

- Oil medium:
  The lubricating properties of the oil strongly influence the friction in the guiding and as a result the stick-slip behavior of the cylinder. Low viscosity oil types require extra attention to seals behavior demands. The increasing demands for the use of environmentally friendly fluids draw special attention to the seal material and its resistance to the used fluid. The use of ester based fluids or poly – glycol's is clearly favored. The vegetable fluids have been known for their fast aging. Further the contact with water will result in the building of a sticky, partly hard substance to the cylinder rod with consequential damage to wiper and seals.
- Stick slip
  As cylinders for bridges are often slender, the natural frequency of the cylinder can equalize to the natural frequency of the bridge. If due to friction a shock movement is enduced in such a situation the whole bridge might start vibrating.
  It is therefore essential that seals and guiding used in a hydraulic cylinder show a minimum Δ between static and dynamic friction. In this way the so-called stick-slip phenomena is avoided.
- Efficiency:
  The efficiency of the hydraulic cylinder is strongly determined by the choice of seals and guiding. As mentioned before the lubrication property of the oil also strongly influences the efficiency of the cylinders. Generally an efficiency rate of > 96% can be considered.

- Safety features:
  As per DIN 19704 it is required to mount a safety block on the pressure loaded side of the cylinder. The safety block basically contains as a minimum 2 safety valves, one logic element and one flow control valve.



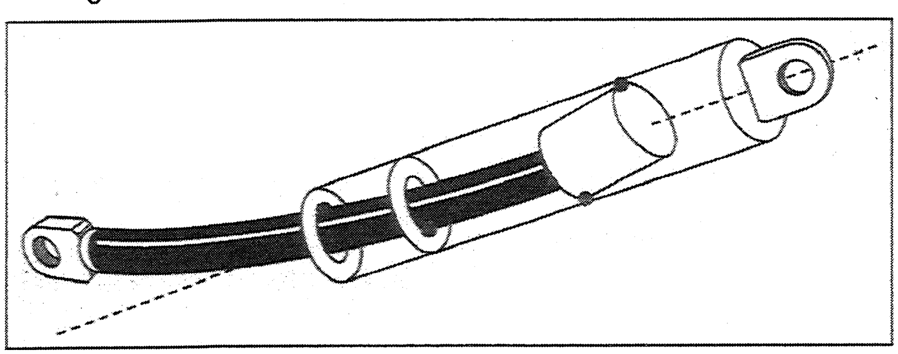
The safety valve DV3 is basically an overload protection for external forces. The safety valve DV1 is limiting the maximum pressure, which can be enduced on the cylinder by the hydraulic system. The maximum pressure limitation of the hydraulic system is secures by the safety valve DV2. The use of a safety block on the cylinder will prevent an uncontrolled movement of the bridge in case of hose rupture.

The cylinder as a construction element

- The DIN 19704 specifies individual safety factors for individual load parameters. Basically the safety factors are related to the static frequency in which a specific load element occurs. The safety for ice load is therefore, for instance, lower than the safety for traffic load. (See table)

<table>
<tr><th rowspan="2">No.</th><th rowspan="2">Type of action</th><th rowspan="2">Actions</th><th rowspan="2">Acc. to</th><th colspan="2">Basic combinations</th><th>Exceptional combinations</th></tr>
<tr><th>Case 1 1)3)</th><th>Case 2 1)3)</th><th>Case 3 1)2)3)</th></tr>
<tr><td>1</td><td>Permanent</td><td>Permanent actions</td><td>5.1</td><td colspan="3">γ_F = 1.35, ψ = 1.0</td></tr>
<tr><td>2</td><td rowspan="10">Variable</td><td>Hydrostatic actions</td><td>5.2.1</td><td rowspan="7">γ_F = 1.35
ψ = 1.0</td><td rowspan="10">γ_F = 1.35
ψ = 0.9</td><td rowspan="12">γ_F = 1.35
ψ = 0.8</td></tr>
<tr><td>3</td><td>Hydrodynamic actions</td><td>5.2.2</td></tr>
<tr><td>4</td><td>Water load</td><td>5.2.3</td></tr>
<tr><td>5</td><td>Ice load</td><td>5.2.4</td></tr>
<tr><td>6</td><td>Live load</td><td>5.2.6</td></tr>
<tr><td>7</td><td>Forces due to inertia</td><td>5.2.7</td></tr>
<tr><td>8</td><td>Changes in conditions of support</td><td>5.2.8</td></tr>
<tr><td>9</td><td>Ice pressure, ice impact</td><td>5.2.5</td><td rowspan="6"></td></tr>
<tr><td>10</td><td>Temperature influences</td><td>5.2.9</td></tr>
<tr><td>11</td><td>Ship friction</td><td>5.2.10</td></tr>
<tr><td>12</td><td rowspan="3">Exceptional</td><td>Leaking of air chambers</td><td>5.3.1</td><td rowspan="3"></td></tr>
<tr><td>13</td><td>Actions under transport, installation and repair conditions</td><td>5.3.2</td></tr>
<tr><td>14</td><td>Actions of the drive in the case of a fault</td><td>5.5</td><td>γ_F see table 5,
ψ = 1.0</td></tr>
<tr><td colspan="7">NOTES:
1) Variable actions only have to be taken into account as present at the same time as specified by the purchaser, if their coincidence is possible.
2) For the exceptional actions no. 12 to 14, only one has to be considered at a time.
3) For other actions, which are to be specified by the purchaser, see 5.4.</td></tr>
</table>

- The cylinder follows a curve when moving. This curve will introduce a rotation of the bearing in the respective hinge points. Depending on the material used as a bearing and its related friction properties this rotation will introduce a bending moment. To reduce the level of stress high load capacity, small size, low friction bearings are favored. The vibration of the due to traffic load may however require enlarged bearings.



Mounting types
As the cylinders will have to follow the curve movement of the hinge point on the bridge, possible misalignment spherical mountings are required. Basically two options can be chosen for cylinder mounting.

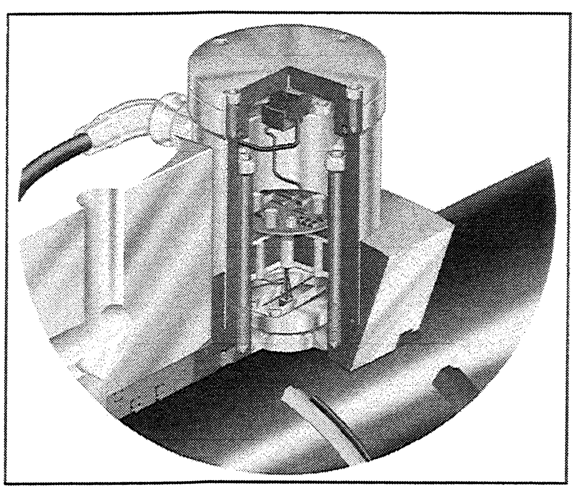
- Eye to eye mounting
- Eye to Cardanic mounting
  The use of a single trunion is not acceptable because it only allows one degree of freedom and thus not compensating possible misalignment.

Position control.
Modern bridge control requires a full monitoring of the opening sequence of the bridge. The position indicator system plays a key role in the monitoring of the bridge.

Different measuring systems are available for the position measurement of the cylinders:
Wire rope systems:
The system is based on a wire rope wound on a drum. The rotation of the drum is measured and translated in a bridge leaf position. The problem with these types of systems is that the position of the rope drum does not necessarily represent the bridge leaf position. In the case of ice on the cable or other debris, the cable can get stuck and the actual position reference is lost. Furthermore these systems are very sensitive to environmental influences. The exposure to the environment will result in corrosion and consequently influence the reliability of such a system. It can be concluded that such system is not favorable for this application.

Integrated measuring devices:
Integrated measuring devices have to be favored as they give a direct feed back on the cylinder position and are not directly subjected to the environmental conditions. Basically two types of integrated measuring devices are available:

- Linear transducers:
  Most of these types of transducers are based on the magneto restrictive principle. The accuracy of these systems and the reliability is high. From this point of view these systems would be very suitable for the use in bridges. Would it not be they have one big draw bag. Next to the limitation in length, these measuring devices will have to be built into the cylinder. This implies that a whole will be drilled in the piston rod and the measuring device is mounted in the bottom of the cylinder.
  This makes servicing of such a system fairly impossible. The way to apply maintenance to these kinds of systems is to dismount the cylinder from the bridge and disassemble the cylinder to such an amount that the measuring system can be replaced. Due to the availability demands of bridges this is an unacceptable draw back.
- CIMS



In the beginning of the nineties a revolutionary new system was introduced. The system is based on sensing serrations in the piston rod located just beneath the Ceramax layer. The sensor is located in the cylinder head just outside the pressurized area. It is fully protected from the environment and readably accessible. This implies that in case of service the sensor can be replaced without disassembly of the cylinder and thus guaranteeing the availability of the Ro-Ro. The CIMS system can be applied to all type of cylinders and is independent of length. As the accuracy lies within 1 millimeter it is an excellent input signal for a synchronization system. The only draw back to this system is that it is not absolute. This means that in case of power failure the position might be lost requiring manual reset of the system. Normally using a battery back up solves this problem, which however does not solve the problem in case of cable rupture. Rexroth Hydraudyne recognized this draw back and is currently in the final stage of developing a new generation of this Ceramax Integrated measuring system. It is expected that in the beginning of 2001 an absolute CIMS system will be commercially available to the market.

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