JACKING AND EQUALIZING CYLINDERS FOR NASA-CRAWLER TRANSPORTER

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For the transport of their spacecraft from the vehicle assembly building to the launch pads at Kennedy Space Centre, Florida, the National Aeronautics and Space Administration (NASA) is using two special crawler transporters since 1965. But for the new generation of Orion- spacecraft which is under development now, a load capacity increase for the crawler transporter of plus 50% was necessary. For this task Hunger Hydraulik did develop new jacking, equalizing and levelling (JEL) cylinders with sufficient load capacity but also with some new features to improve the availability, reliability and safety of this system. After design approval and manufacture of the cylinders they have been tested in a special developed dynamic test rig and after passing this the cylinders had to prove their performance in the crawler transporter itself.

The two crawler transporters at Kennedy Space Centre were built from 1963 - 1965 to transport the fully assembled Saturn V rocket together with the Apollo spacecraft and the launch platform from the assembly building to the launch pads. Later the crawler transporters were used for Spacelab, Apollo-Soyuz and all Space Shuttle missions. For this job the crawler transporters are designed with eight chain tracks, two in each under-carriage, and with dimensions of 40 m length and 35 m width. The maximum load capacity was specified to 6.000 ton to be handled by the hydraulic jacking, equalizing and levelling (JEL) system. This JEL- system was designed with 16 single acting cylinders, four of them in each under-carriage. With this JEL- system the crawler transporter can lift up the completely equipped launch platform from its parking slot in the vehicle assembly building, can level it during the transport and especially for the launch pad ramp drive and can drop it on the launch pad slot. To realize these functions the hydraulic cylinders have a stroke length of 2 m which also covers the compensation of the 5° angle of the launch pad ramps. To allow the original JEL-cylinders the required freedom of motion during steering and levelling operation spherical bearings have been mounted on rod end and bottom. The load control was done by remote controlled load control valves on each cylinder. It was also possible to hydraulically shut off a single JEL-cylinder and to maintain the load with the remaining three other JEL-cylinders for emergency operation. **Figure 01** shows the installation situation of the original JEL-cylinders in one under-carriage. The central hydraulic power unit is installed in the center of the load frame structure and provides all sixteen JEL-cylinders with hydraulic energy.

Now, after 50 years in duty the crawler transporters were completely overhauled and in doing so the load capacity of one of the crawler transporters should be increased by plus 50%. Beside other adjustments the JEL-cylinders had to be exchanged. The modifications will enable the NASA to use the crawler transporter to continue supporting human spaceflight for another 20 years [1].

SCOPE OF WORK

The specification for the new JEL-cylinders was worked out by NASA but also some proposals from Hunger Hydraulik regarding the design concept of the new JEL-cylinders were considered and taken over. Beside the load capacity increase the main focus was directed to a high safety level and a high reliability of the JEL- system. The main requirements for the new JEL-cylinder project were:

- Load increase for the JEL- system of plus 50% keeping the existing hydraulic power unit with given pressure and oil flow parameters
- Using the same installation space and mounting interfaces in the crawler transporter
- Improving the solution for the spherical bearings
- Offering a multi- level safety concept for the hydraulic load control
- Easier installation and handling of the JEL-cylinders
- Enhanced corrosion protection for the piston rods in the offshore-like environment at Kennedy Space Center
- Engineering and manufacture of a one-to-one scale dynamic test rig.

Based on these requirements a risk analysis with handling options was carried out for the existing JEL-cylinder design as well as for the new cylinder drafts. This did analyze the effect of different failures like for example a main seal malfunction, a pressure pipe or pressure hose rupture or a break of a spherical bearing or pin. As a result it could be shown that the new JEL-cylinder design improves the system behavior and reduces the consequences for any of these malfunctions to make sure that a transport task can be finished without delay and without taking an increased risk.

01 Installation situation of the old JEL- cylinders in one under-carriage

DESIGN SOLUTION FOR THE NEW JEL-CYLINDERS

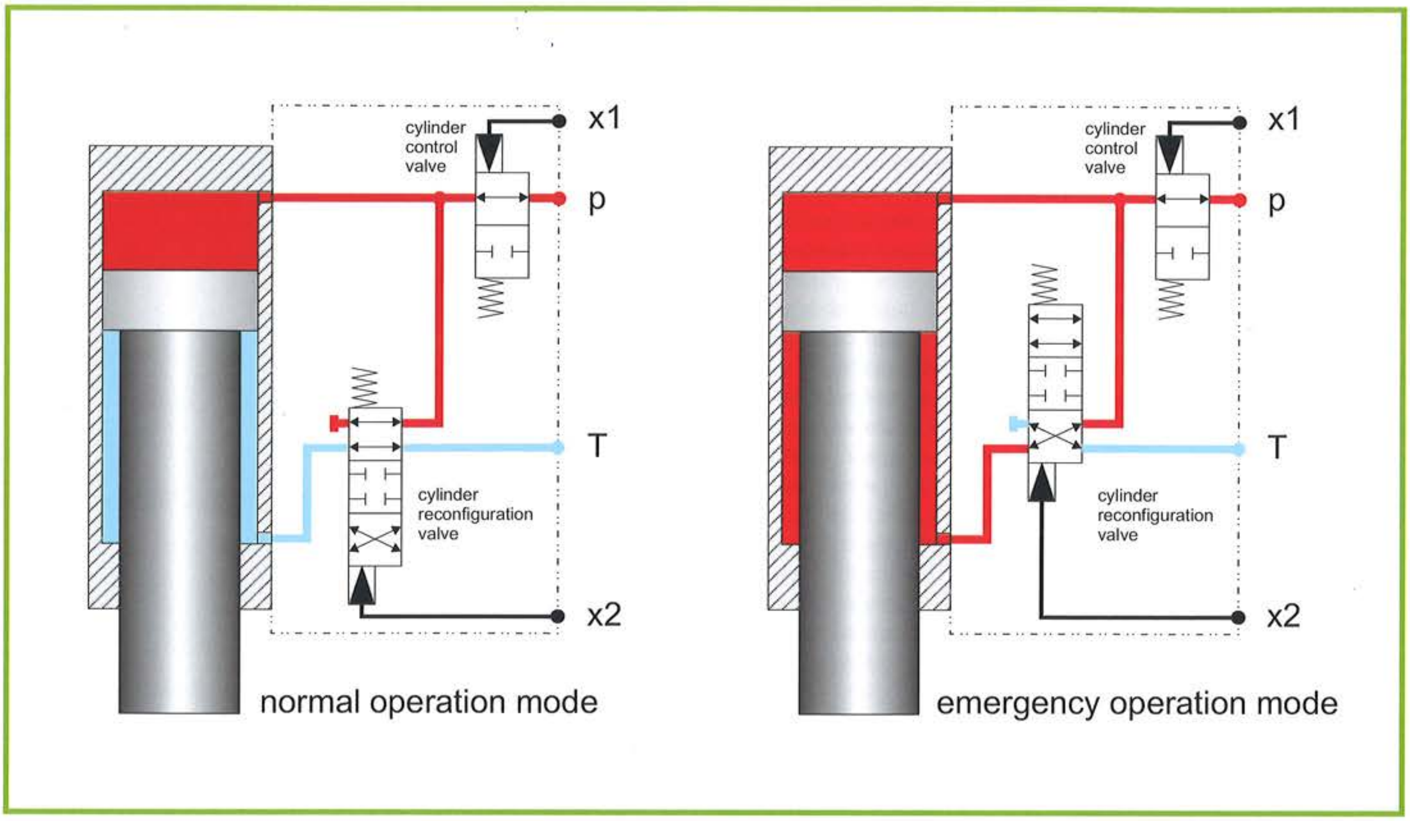
Based on the conditions mentioned above a cylinder design was developed and introduced to NASA which can fulfill all the requirements. After detailed investigation and after getting the preliminary approval for the design and the calculations two prototype cylinders were built to prove their manufacturability, performance and quality. Later on, after the tests have been successfully completed, the working JEL-cylinders were manufactured for the first crawler transporter.

The new JEL-cylinders were designed and calculated according to ASME standards with flanged cylinder head and bottom for easy maintenance. To realize the by 50% increased load capacity under the use of the same power unit in the crawler transporter it was necessary to increase the diameter of the cylinders accordingly. At the same time the space limitations in the given crawler transporter structure needs to be considered. Instead of the original spherical bearings with pin and clevis now spherical ball joints in maintenance free execution were used. Additionally the mounting interfaces to the crawler transporter were equipped with adaptor plates with fast mounting interlocks. Instead of in-pipe mounted safety valves a hydraulic manifold block was considered on each JEL-cylinder.

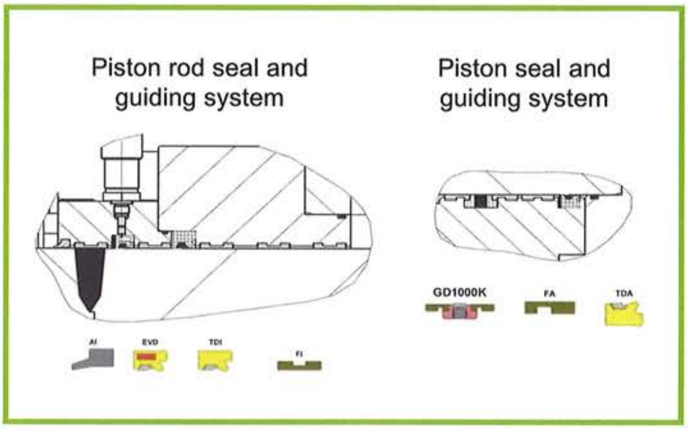
Even the new JEL-cylinders also have to lift and lower loads under gravity only they are designed as double acting cylinders now. This offers some advantages compared to the old cylinders designed as single acting ones. On the one hand the loaded seal is the piston seal now which is surrounded by the controlled and clean hydraulic fluid and is more protected from environmental influences. On the other hand the piston rod seal can now act as a secondary emergency seal if the JEL-cylinder would be used in single operation mode controlled by a special set-up in the manifold block. To activate the emergency mode the cylinder reconfiguration valve needs to be activated only. To have lowest possible load variation in this emergency mode the rod diameter was designed as big as possible. **Figure 02** shows the hydraulic set-up of the JEL-cylinder in principal.

SEAL DESIGN

To hold the load under all circumstances and to guarantee a stroke movement which is free stick slip effects or other vibra-



02 **Principle of hydraulic set-up with normal and emergency mode**



03 **Seal and bearing elements in cylinder head and on piston**

tions the seal arrangement in the JEL-cylinders is of a very high importance. The dynamic seals on piston and in the cylinder head were mainly selected out of the Hunger DFE GmbH standard seal program and arranged as shown in the example in **Figure 03** [2]. Because the JEL-cylinders are always loaded in pushing direction the main piston seal is TDA type with orientation to the piston chamber. A secondary GD1000K type seal offers extra safety and seals the piston from the annulus chamber side in case of installation work where the stroke adjustment is done by pressurizing this side. The seal arrangement in the cylinder head consists of a TDI type seal and a secondary, externally adjustable seal, called EVD. Together with the other measurements the following operation mode can be realized to seal the JEL-cylinder:

- Normal operation: The TDA piston seal (with the GD1000K in cascade) seals against the load pressure. The annulus chamber is connected to tank pressure only.
- Emergency operation 1: The TDI rod seal seals against the load pressure in case of a failed piston seal. Piston chamber and annulus chamber are hydraulically connected.
- Emergency operation 2: The EVD rod seal seals against the load pressure in case of a failed piston seal and a failed TDI rod seal. Piston chamber and annulus chamber are hydraulically connected.

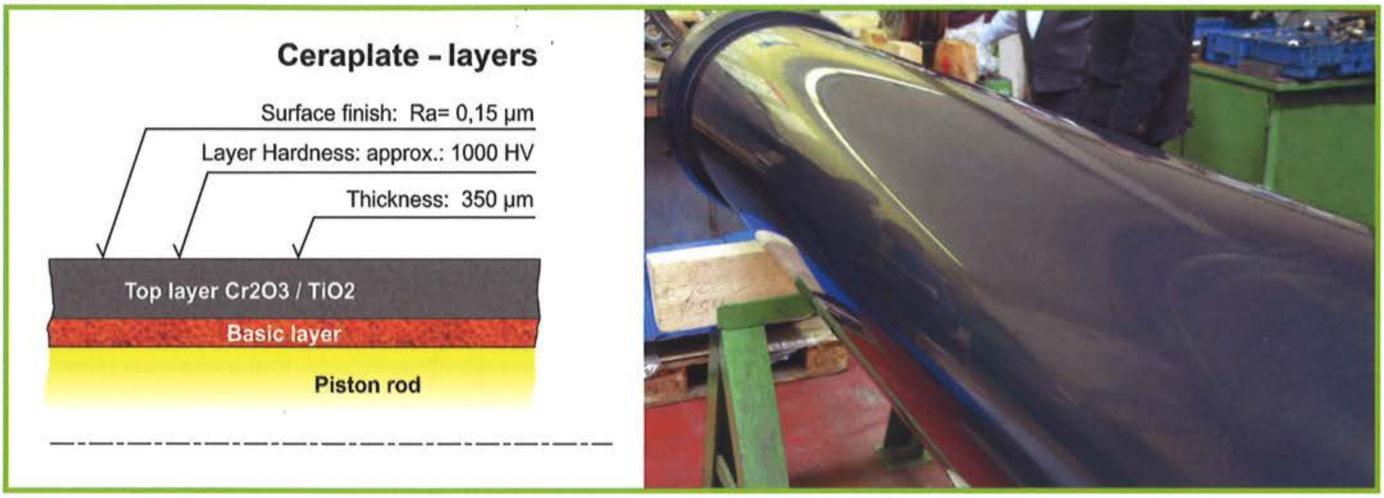
To guide the piston and the piston rod as well as to take any possible side load FI / FA type plastic compound bearing elements are used. They consist of a POM-PTFE-bronze compound material and offer low friction and stick slip free movement especially at low speed movements. The special shape of the bearing elements grants a 3 mm clearance between the relative to each other moving parts and can at the same time directly support the seal elements in axial direction without any extrusion gap.

PISTON ROD COATING

To protect the piston rods in the offshore like sea atmosphere at Kennedy Space Center they are coated with the thermal sprayed metal oxide coating Ceraplate [3]. This coating provides an enhanced corrosion protection also when the rods are exposed to the sea atmosphere for a longer time when the crawler transporter is not in use. **Figure 04** shows the layer composition and properties of the Ceraplate coating. The performance of the Ceraplate coating is tested and certified by independent institutes with regards to layer composition, hardness and corrosion resistance according DIN EN ISO 9227.

SPHERICAL BEARINGS

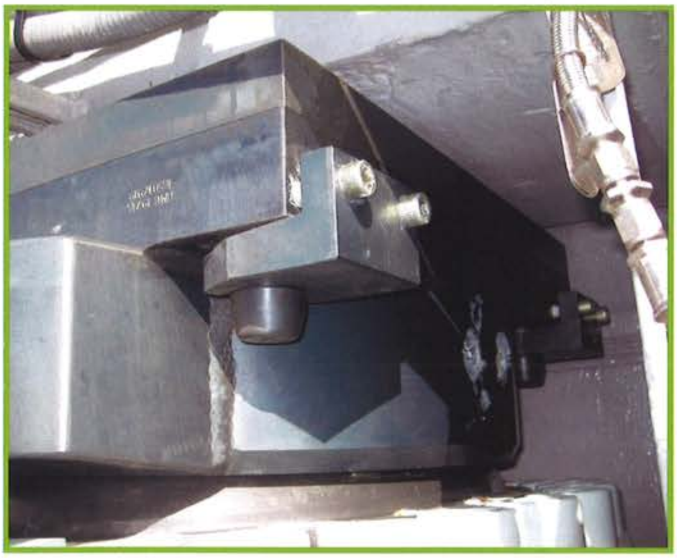
To improve the live time and reliability of the JEL-cylinder bearings the design was changed from steel – steel spherical ball bearings with clevis and pin to spherical ball joints in maintenance free



04 Ceraplate piston rod coating – layer composition and JEL- cylinder rods

05 Old and cracked bearing and new bearing design with H- Glide lining

06 JEL- cylinder handled with the lifting fixture



07 Mounting interface with fast locking wedges

execution. While the old bearings have cracked sometimes the new design should be more robust and should withstand even overload conditions without problems. The spherical ball joints offer an increased bearing area which reduces the contact stress in the material and the interfaces and this design is also free of bending stresses in all loaded parts. The bearing material is a maintenance free Hunger H- Glide lining in combination with a hardened steel ball as a counterpart. It allows a free tilting of 7° in any direction with a maximum compressive strength in the H- Glide of 160 MPa. To keep both bearing parts together an inner retention pin is used. To avoid uncontrolled rotation of the JEL-cylinders the bottom side spherical ball joints are equipped with an anti-rotation device. In Figure 05 the old and the new design are shown.

08 **JEL- cylinder in the load frame on the hydraulic test rig**

HANDLING AND INSTALLATION

Because of its size any service and maintenance of the crawler transporter is typically carried out outdoors by using mobile cranes for handling of heavier parts. In case of the JEL-cylinders the installation space requires to put them under the upper load frame structure which is difficult if the cylinder is hanging on a crane hook. Therefore a lifting fixture was developed which allows a much easier handling and installation of the JEL-cylinders in the crawler **(Figure 06)**.

Furthermore the mounting interface between the crawler transporter and the JEL-cylinder were modified with adaptor plates with fast mounting interlocks. First the adaptor plates only will be flanged to the crawler transporter structure whereat a good accessibility is given. In a second step the JEL-cylinders will be lift in position and secured with fast locking wedges **(Figure 07)**.

TESTING THE JEL-CYLINDERS

To prove the performance of the new design of the JEL-cylinders an extensive test program had to be developed and executed. This test program did consist on static tests, dynamic full load tests as well as on real application tests with the crawler transporter.

09 **Dynamic test rig with JEL- cylinder and part inspection after test run**

The static tests were carried out on the hydraulic test rig at Walter Hunger GmbH & Co. KG which was extended by a static load frame which did allow full pressure tests of the JEL-cylinders not only in the end stroke positions but also in a mid-stroke position **(Figure 08)**. Additionally all functions of the manifold block were tested as well as the freedom of motion of the spherical ball bearings.

To carry out dynamic tests with the JEL-cylinders under full load a dynamic test rig was developed and build which consist of a vertical load frame with moveable mid support and load cylinder, a hydraulic power unit with two independent controllable hydraulic axis as well as of the necessary control and recording hard- and software. The JEL-cylinder was installed in the lower part of the test rig in one axis with the load cylinder as shown in **Figure 09**.

The dynamic test program did contain sequences of full stroke cycles, smaller oscillations and load variations. Also emergency load conditions could be tested. During all tests the system parameters as well as the JEL-cylinder parameters like pressure, stroke position, friction, number of cycles etc. were recorded for later evaluation. After finishing the dynamic test program each of the tested JEL-cylinders were dismantled and inspected in detail **(Figure 09)**. Based on these findings smaller design adjustments for the manufacturing units were made and also an evaluation of the life time, reliability and performance of each JEL-cylinder part could be made.

DRIVE TESTS WITH THE CRAWLER TRANSPORTER

To prove that the new JEL-cylinders will fit into the given crawler transporter structure and to their functionality and performance the two prototype cylinders were installed in one under-carriage unit instead of two old cylinders. In doing so the handling was tested as well as all the interfaces. After first lifting tests the crawler transporter was driven from the vehicle assembly building the whole way to one launch pad and back. This test drive contained cornering, lifting operations and a ramp ride and could finished successfully **(Figure 10)**. The results were analyzed, discussed and necessary changes were taken over for the production units of the JEL-cylinders.

After manufacturing and testing the working JEL-cylinders the first crawler transporter was completely equipped with them and extensive test rides have been carried out. The final drive and load tests could be finished successfully so that the first crawler transporter is ready for future NASA- missions **(Figure 11)**.

Images: *Figures front page down, 05 left and middle as well as 06 NASA, rest Hunger*

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10 Cornering with the prototype JEL- cylinders at Kennedy Space Center

11 NASA- Crawler transporter with new JEL- cylinders

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