Jacking and Equalizing Cylinders for NASA- Crawler Transporter

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Abstract

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. First developed for the Saturn V rocket the crawler transporters have been sufficient for all following generations of space ships so far. 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 one-to-one scale dynamic test rig and after passing this the cylinders had to prove their performance in the crawler transporter itself. This article describes the general application and introduces the technical requirements of this project as well as the realized solution.

KEYWORDS: hydraulic cylinder, actuator, crawler, spacecraft transporter, equalizing system, lifting system, hydraulic safety block, externally adjustable seal, piston rod coating, spherical ball joint, maintenance free bearing, test rig

1. Introduction

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 m_L= 6.000 ton to be handled by the hydraulic jacking, equalizing and levelling (JEL) system /01/. This JEL- system was designed with sixteen 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 x= 2.000 mm which also covers the compensation of the 5° angle of the launch pad ramps. **Figure 01** shows a ramp ride of the crawler transporter together with a space shuttle on a horizontally levelled launch pad.

Photo: NASA

Figure 01: Crawler transporter with launch pad and space shuttle on ramp ride

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 02** shows the installation situation of the old 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 should be increased by plus 50%. Beside other adjustments the JEL- cylinders had to be exchanged and Hunger Hydraulik did win the tender for this job. Using the improved vehicles, NASA will send astronauts farther than ever before, first to an asteroid, and onwards to Mars. The modifications will enable the crawler transporter to continue supporting human spaceflight for another 20 years /1/.

Photo: Hunger

Figure 02: Installation situation of the old JEL- cylinders in one under-carriage

2. Scope of Work

The specification for the new JEL- cylinders was worked out by NASA based on the requirements for the new rocket and space ship generation. 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 in the offshore- like environment
- 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:

- main seal malfunction
- pressure pipe or pressure hose rupture
- manifold block malfunction
- break of a spherical bearing or pin.

The new JEL- cylinder design should improve the behavior and 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.

3. 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.

3.1 General JEL- cylinder design

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 03** shows the hydraulic set-up of the JEL- cylinder in principal.

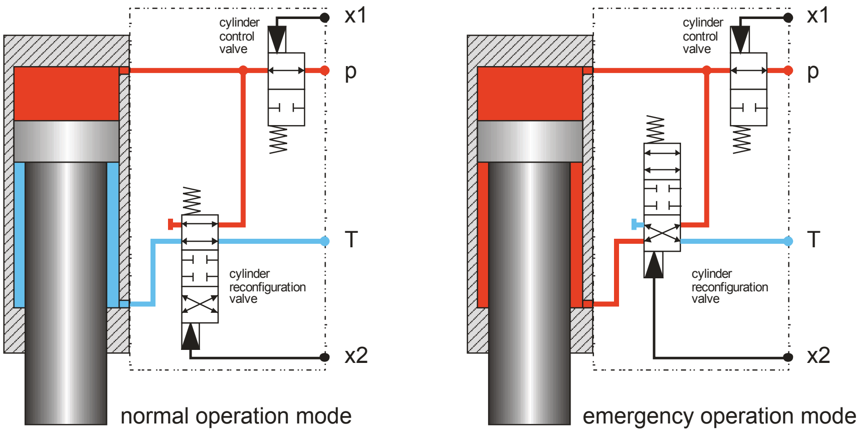


Figure 03: Principle of hydraulic set-up with normal and emergency mode

3.2 Dynamic seals

To hold the load under all circumstances and to guarantee a stroke movement which is free stick slip effects or other vibrations 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 04** /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:

1. 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.

2. Emergency operation I → The TDI rod seal seals against the load pressure in case of a failed piston seal. Piston chamber and annulus chamber are hydraulically connected.

3. Emergency operation II → 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.

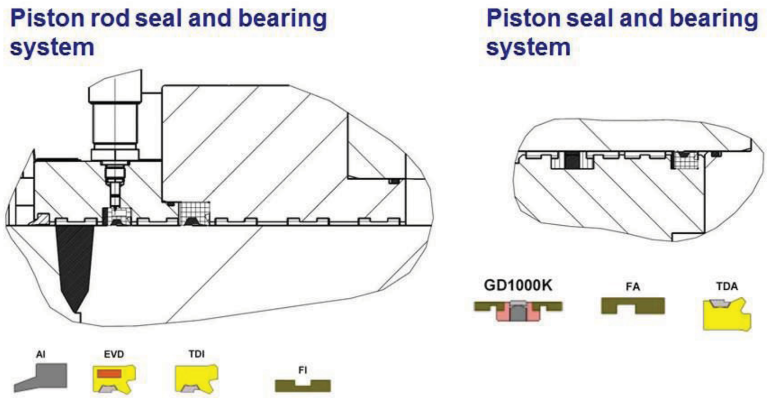
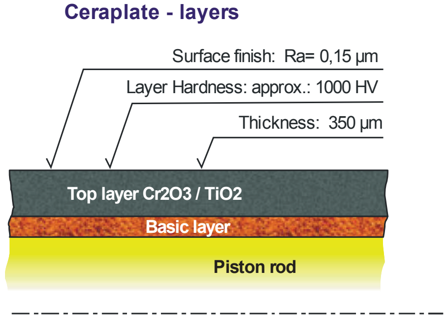


Figure 04: Seal and bearing elements in cylinder head and on piston

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.

3.3 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 05** 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.



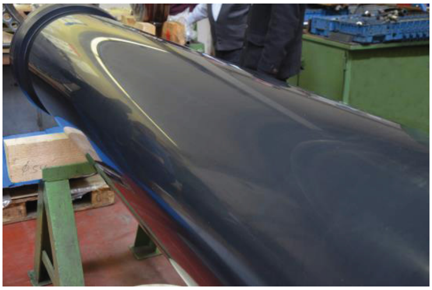
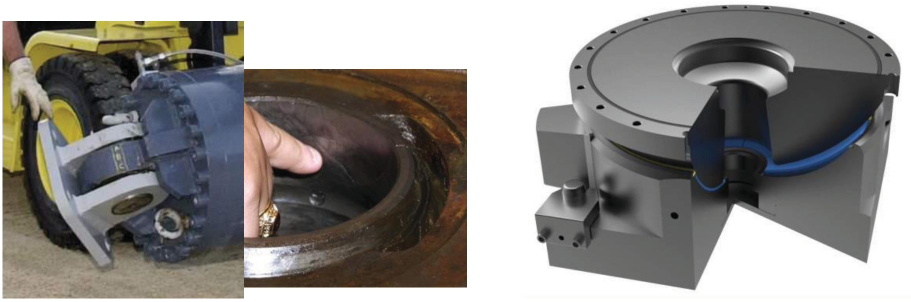


Photo: Hunger

Figure 05: Ceraplate piston rod coating – layer composition and JEL- cylinder rods

3.4 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 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 α= 7° in any direction with a maximum compressive strength in the H- Glide of σ_D= 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 06** the old and the new design are shown.



Photos: NASA Image: Hunger

Figure 06: Old and cracked bearing and new bearing design with H- Glide lining

3.5 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 07**).

Photo: NASA

Figure 07: JEL- cylinder handled with the lifting fixture

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 08**).

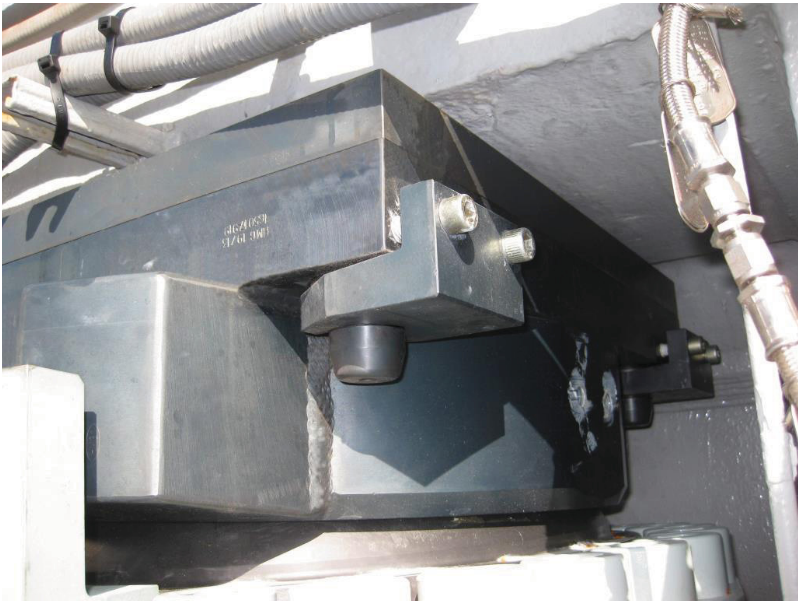


Photo: Hunger

Figure 08: Mounting interface with fast locking wedges

4. 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.

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 09**). Additionally all functions of the manifold block were tested as well as the freedom of motion of the spherical ball bearings.

Photo: Hunger

Figure 09: JEL- cylinder in the load frame on the hydraulic test rig

4.1 Dynamic test rig design and test program

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 10** on the left hand side.

Photos: Hunger

Figure 10: Dynamic test rig with JEL- cylinder and part inspection after test run

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 10). 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.

4.2 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 wedges (**Figure 11**). The results were analyzed, discussed and necessary changes were taken over for the production units of the JEL- cylinders.

Photos: Hunger

Figure 11: Cornering and ramp ride with the prototype JEL- cylinders during the test drive

5. Conclusions and forecast

With this project the task of developing new JEL- cylinders for NASA’s crawler transporter with increased load capacity could be fulfilled. Beside this the safety of the hydraulic load control system could be improved. All carried out tests did confirm the performance of the new JEL- cylinders and they got approved and accepted by NASA for the final installation in the crawler transporter. Future drive and load tests at Kennedy Space Centre will further investigate and evaluate their performance before the first space craft will be moved to the launch pad. The team of Hunger engineers will continue to accompany this project.

6. References

/1/ NASA's Giant Crawlers turn 50 Years Old, Pivot Toward Future Exploration http://www.nasa.gov/content/nasas-giant-crawlers-turn-50-years, 23.02.2015

/2/ Hunger DFE Product Range, Hunger DFE GmbH, Würzburg, 2015

/3/ Piston Rod Coatings, Walter Hunger GmbH & Co. KG, Lohr am Main, 2010

7. Nomenclature

m_L	Load capacity of the crawler transporter	ton
R_a	Surface roughness	µm
x	Stroke length	mm
α	angle	°
σ_D	Compressive strength	N/mm²