Annex A

A conceptual design of a facility has been produced by F4E and analysed by IO

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Presentations

Pre- compression ring test machine conceptual design

This report outlines the main concepts of a testing equipment capable to assess the strength and thestiffness of the ITER pre-compression rings

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REPORT

ON

Pre- compression ring test machine conceptual design

Abstract

This report outlines the main concepts of a testing equipment capable to assess the strength and the stiffness of the ITER pre-compression rings.

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	Pre compression Ring	PCR
	Pre compression ring testing machine	PCRTM

2 APPLICABLE DOCUMENTS

Ref number	Doc Number	Doc number and document title..

3 REFERENEC DOCUMENTS

Ref number	Doc Number	Doc number and document title..
[R 1]	March, 4 ,2011	ENEA PC-RINGS TESTING FACILITY
[R 2]	PCRTM stress analysis	

4 INTRODUCTION

The Pre-compression Rings (PCRs) of ITER represent one of the largest and most highly stressed composite structures ever designed for long term operation at 4K. Six rings, each 5m in diameter and 337 x 288 mm in cross-section, will be manufactured from S2 fibre-glass/epoxy composite and installed three at the top and three at the bottom of the eighteen “D” shaped toroidal field (TF) coils to apply a total centripetal pre-load of 74 MN per TF coil.

The TF coil case is equipped with inter-coil structures serving to assemble 18 TF coils toroidally and to ensure their mechanical strength and stability during energization. These structures are: Poloidal Shear Keys (IIS), Outer Inter-coil Structures (OIS), Intermediate Outer Inter-coil Structures (IOIS) and Inner Leg Inter-coil Structures (ILIS). A pair of TF Coils is shown in Figure 1

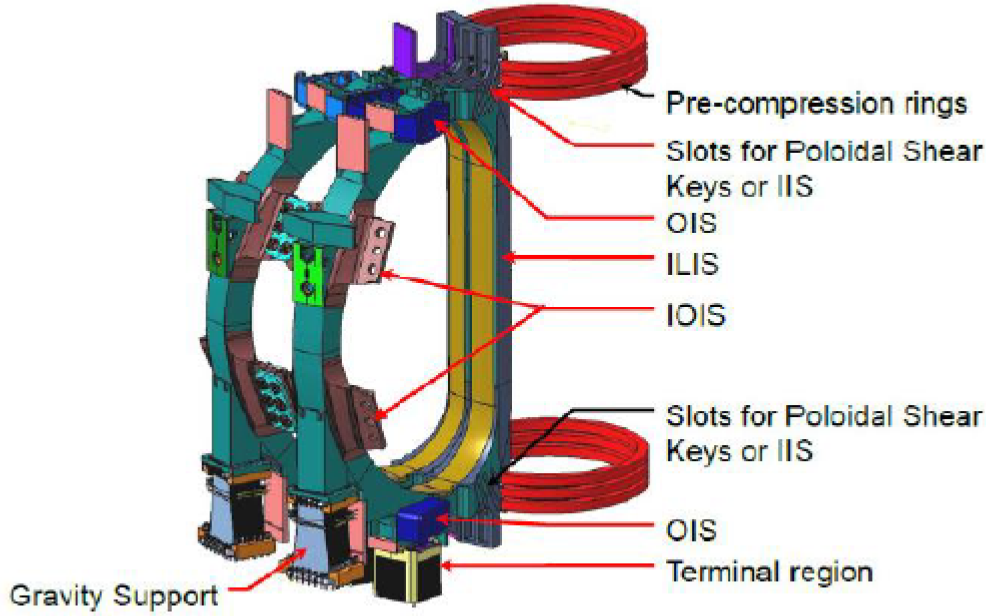

Figure 1

The PCR’s are connected to the TF coils through ‘Superbolts’ which pass from the TF coil flanges to the Pre Compression Counter Flanges (PCCF’s) as shown in Figure 2 below. Each PCR will be pre-loaded through tightening of the ‘Superbolts’ at Room Temperature (RT) reaching up to 60 MPa radial compression resulting in up to 400 MPa average hoop tension. The ITER structure is then cooled to 4K for the operation. The PCRs are designed to withstand various thermo mechanical load cycles and ionizing radiation in the order of hundreds kGy during the entire ITER operation life of 20 years holding the load without degradation.

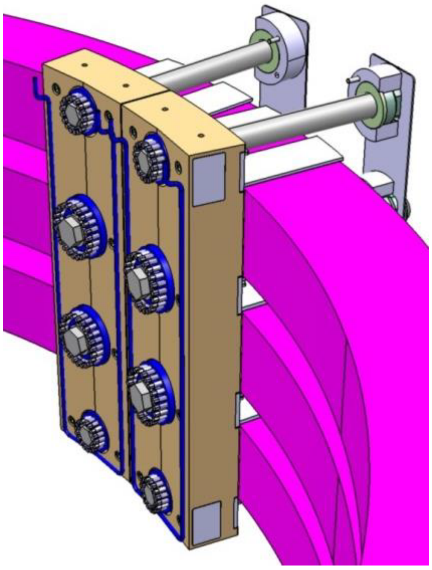

Figure 2

This documents presents the conceptual study of a testing machine suitable to assess the strength and the stiffness of one fiberglass pre-compression ring

5 BACKGROUND

The need to test each PCR before the installation is originated by the importance of the PCR function combined to its very low accessibility. In fact, in the Iter assembly sequence the bottom pre-compression rings have to be installed in the very first phases of the assembly sequence. Once in place, the bottom Pre-compression rings are trapped in the bottom part of the machine and can't be replaced . In order to reduce the consequences of a ring failure and also to cover the machine lifetime of 20years, a spare set of three rings will also be installed below the vacuum vessel for future installation. As a measure of risk mitigation against a possible ring failure it has been proposed to design and manufacture a testing device that , working at room temperature, can assess the mechanical characteristics of the PCR before the installation. The machine concept is inspired to a similar machine built during the R&D phases that is capable to test reduced scale pcr rings .Figure 3 shows a picture of the testing device still in operation nearby the ENEA fusion lab premises in Frascati Italy [R 1].

Figure 3 Mock up testing machine

6 MAIN REQUIREMENTS

The PCR testing machine (PCRTM) main requirements are the following

6.1 PUSHING CAPABILITY

The machine maximum pushing capability is set to 36kTon. This load is being delivered to the PCR in 18 locations . The PCR under test will be than loaded with 2000 tons on each of the 18 locations

6.2 DISPLACEMENT AND STROKE

The radial motion measured from the home position (all actuators full retracted) is 75 mm . The first 5 mm of stroke are used to allow the installation of the PCR in the machine. The contact between the pusher and the ring will appear at +5mm radial stroke.

The load will be gradually increase until the maximum load or the maximum displacement is reached

6.3 TYPE OF CONTROL

The actuator displacement will be controlled in a closed loop .

36 independent position control loops will be used. For this reason each actuator will be equipped with a suitable displacement sensor feed backing the position signal to the control board . The difference in stroke of any actuator shall not exceed 0.1 mm at all time regardless of the force the cylinder is applying to the ring

Fluid pressure in the cylinder chambers will be continuously monitored and recorded. The operating pressure will be set up from 50 to 700 bar by the operator with an adequate pressure regulator valve in a way to avoid any unwanted over load .

6.4 OPERATING PRESSURE

The facility max operating pressure is 700 bar . The operator will set the operating pressure from 50 to 700 bar in accordance to the testing program

6.5 EXTENSION SPEED

The actuating speed during the extension phase can be as slow as 1mm/min. The test will be performed in several steps followed by a rest time of at least 10 s. The operator might set the motion step from 0.1 to 5 mm max according the test program

6.6 RETRACTION SPEED

The actuator will be retracted in steps from 0.1 to 5 mm. The retracting force shall not exceed 10 ton. The retracting speed shll not exceed ten times the expansion speed . Maximum retracting speed = 10mm/min

During the actuator retraction the maximum the maximum stroke difference of 0.1mm shall be guaranteed at all times regardless of the force the cylinder is delivering to the ring

6.7 DATA ACQUISITION

An independent data acquisition system will be in charge to collect all the facility parameters and store them into an appropriate database. A User Graphical interface will present main facility parameters to the operator with a refresh rate of at least 2 Hertz.

7 MACHINE PERFORMANCE

As already mentioned the PCRTM is supposed to be capable to deliver 36kTon of radial force to the PCR with a maximum radial displacement ripple of 0.1 mm.

The test will be performed in steps in a quasi-stationary mode. Displacement request will be set, pressures and load will be read by appropriate instrumentation.

The machine main capabilities are summarized in Figure 4

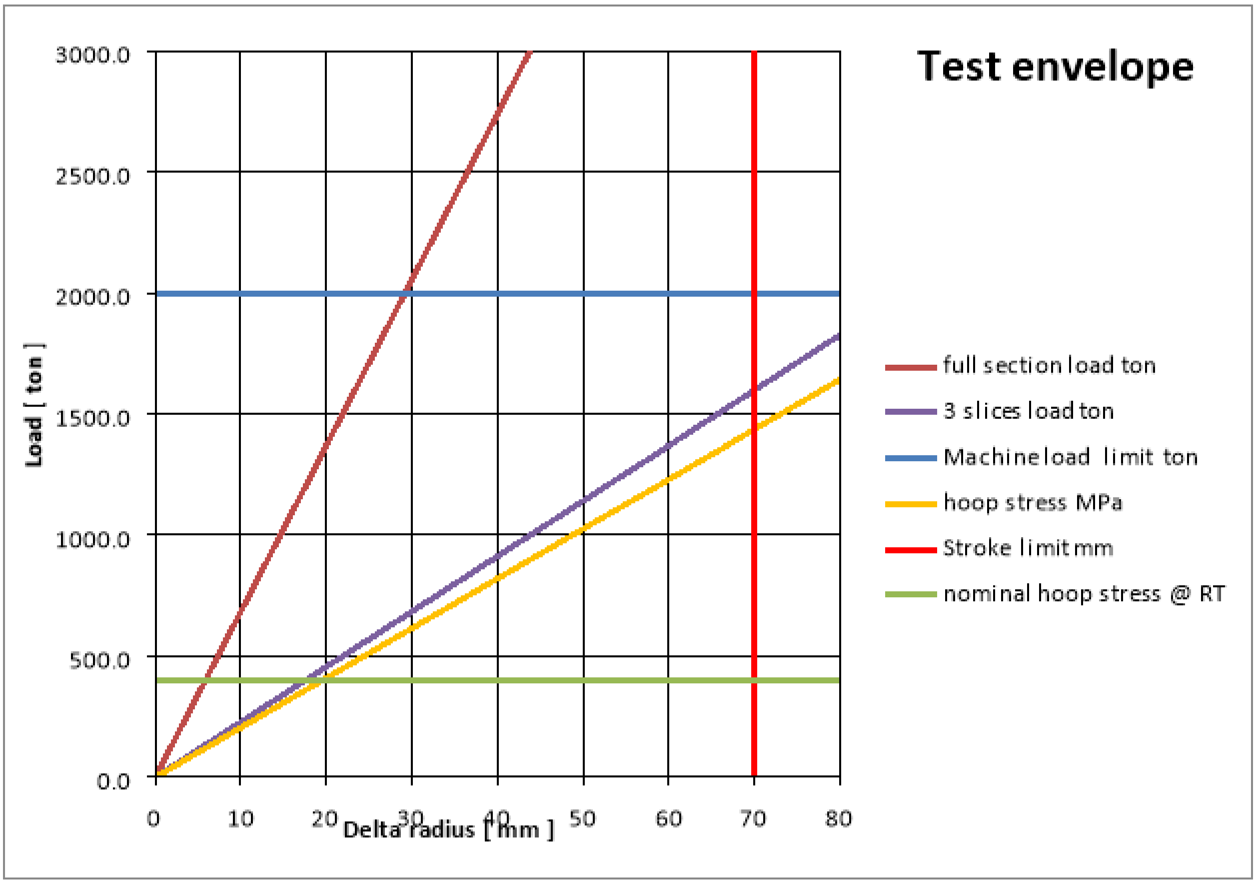

Figure 4 Machine performance

7.1 FULL PCR SECTOR

According the present design the PCR is composed by 3 slices stacked together. In case a full section ring is being tested the load limitation will come first . In this condition the maximum radial load will be 36Ktons producing an average equilibrium hoop stress of 600 Mpa in the ring.

It has to be noticed that this loading condition is 1.5 times higher the nominal working condition where the average hoop stress is supposed to be smaller-equal to 400 Mpa. This maximum load condition is achieved increasing the ring internal diameter by 60 mm . According to the PCR specification the load given by the machine in this condition is not sufficient to produce the PCR failure that should not appear below 1200 Mpa

7.2 ONE SLICE TEST

The PCRTM can also test one PCR slice . In this case the stroke limitation (Δr= 70 mm) will take place before the load limitation. The slice corresponding h average hoop stress is1400 Mpa Approx. and it is supposed to be sufficient to bring the PCR slice to rupture

8 TESTING MACHINE CONCEPTUAL DESIGN

8.1 MECHANICAL LAYOUT

Figure 5 shows a pictorial view of the machine layout . The device is based on 36 Synchronized hydraulic cylinders (actuators) that are radially assembled on a central column shown in Figure 6. The actuators are coupled in pairs. Each pair constitutes a double body actuator see Figure 7.

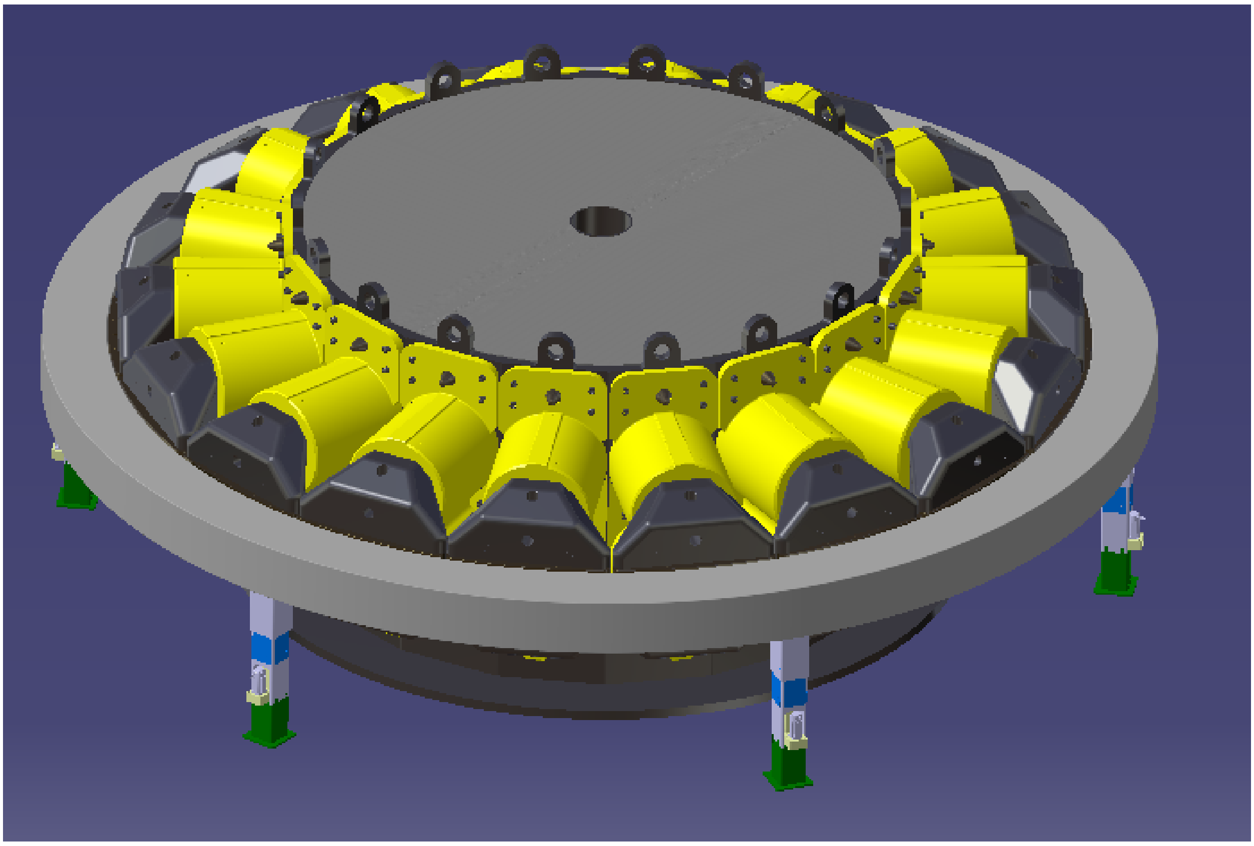

Figure 5 PCRTM lay out

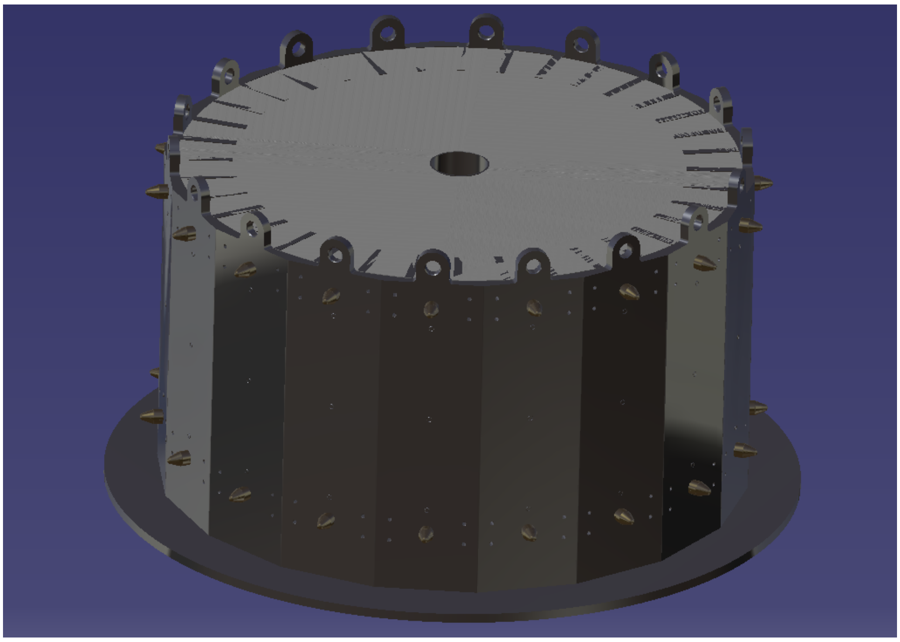

Figure 6 Central column

The forces delivered by the two piston rods are combined together by means of a solid steel part called the spreader.

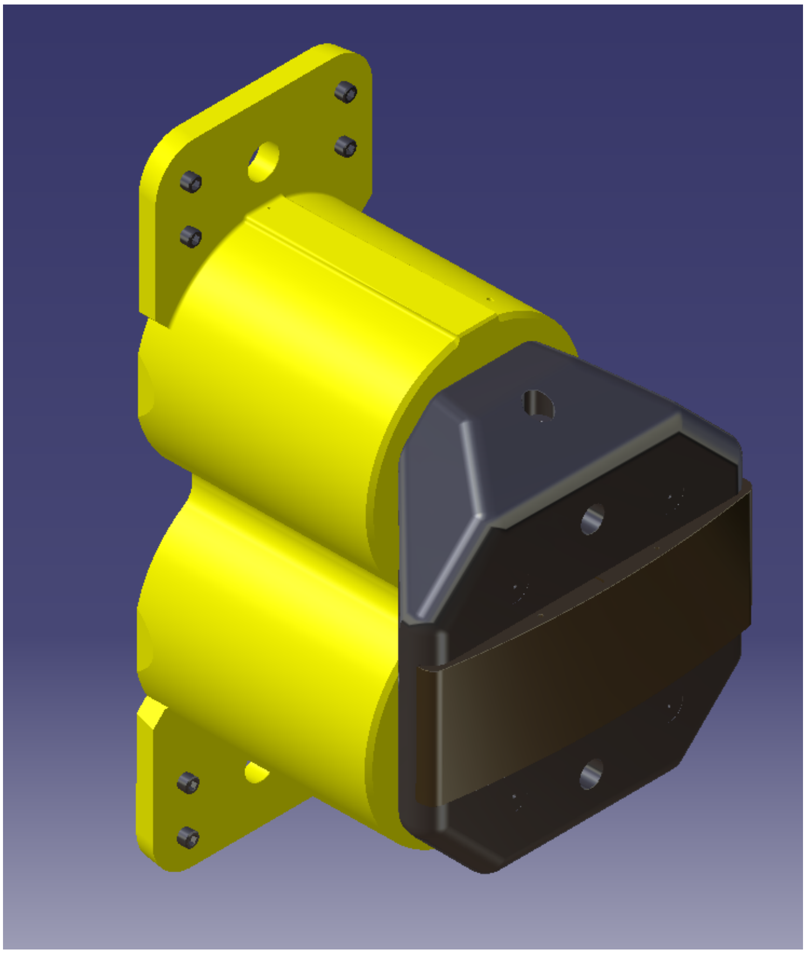

Figure 7 Twin cylinder assy

An horizontal slot in the spreader front surface machined out to host the PCR mating parts is supposed to transfer the load from the spreader to the PCR inner surface. This part has been designed to be removable to be shape customized to find the best match between the PCR internal surface and the spreader. This optimization process has not be performed yet, but it will done find the best tuning in terms of radial stresses thus to reduce as much as possible any contact stress concentration.

Each cylinder actuator is equipped with a displacement sensor used by the power pack control system to modulate the control valves aperture in charge to close the position loop control. #6 magneto-strictive displacement sensors are supposed to be used to obtain the displacement control of each individual axis. This features will not only guarantee a good parallelism of the motion but as well will give the possibility to induce a certain level of cross section twist if needed.

A special attention has to be paid in the load transmission from the actuator rod to the spreader socket. For the sake of simplicity it has been decide to interpose a soft aluminium cap that will give the necessary compliance by the two systems to limit the bending moment on the actuator shaft and consequently the seals wear .

The internal column of the machine Figure 6 is made of a 50 mm rolled sheet metal contains a concrete block that will be casted on site at the installation time. The role of this concrete block is to distribute and balance the forces transmitted by the 36 actuators and to increase the steel column stiffness . It has to be noticed that for a sound operation of the machine it is essential that a very good parallelism of the two cylinder axis has to be obtained at all times. Being the two cylinders machined together by CNC machine centre, the parallelism by the two axis can be maintained below 0.02 mm . Furthermore the structural collaboration of the two cylinder bodies will significantly increase the global stiffness of the assembly with a positive impact on the radial stress distribution on the central column that in turns is essential to maintain the two cylinder axis parallel during operation operations.

8.2 HYDRAULIC CIRCUIT

There are many possibilities to control the stroke of each cylinders. Each type of hydraulic circuit has to be simulated and tested on small scale @ 700 bars to test dynamic transition effect due to the valve opening that are hard to be simulated.

As any other hydraulic circuit, the power pack is composed by pump, check valves, pressure relief valves thank filters heat exchangers etc. but the most qualifying and critical component in the system is the directional valve feeding the two cilndr chambers . Previous experience made on the reduced scale testing machine [R 1]0

showed that the use the use of a good combination of Proportional valve displacement sensor and low friction seal pack is essential for the quality of the control. In particular it is well known that proportional valves against check valves are definitely more accurate in control the fluid flux that in turns control the piston movement. For this reason the proportional directional valve is proposed as the key element of the circuit.

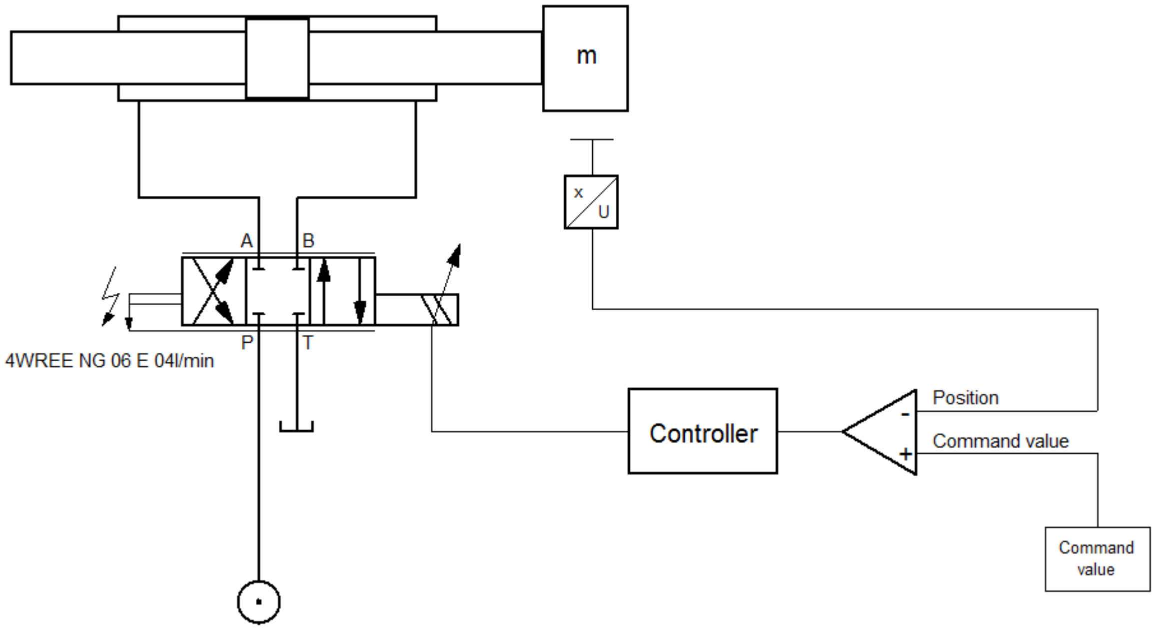

Figure 8 Control logic

Depending on market availability that for valves with an operating pressure higher then 700 bar is very limited to different possible circuit are here proposed.

8.3 3/3 CIRCUIT

Figure 9 shows the basic concept of a circuit based on a 3/3 valves . This type of valve has 3 position of the spool and 3 channels. The transition between one position and the others is proportionally controllable. This valve is very robust but it doesn't allow the change of direction in the fluid line. For this reason the

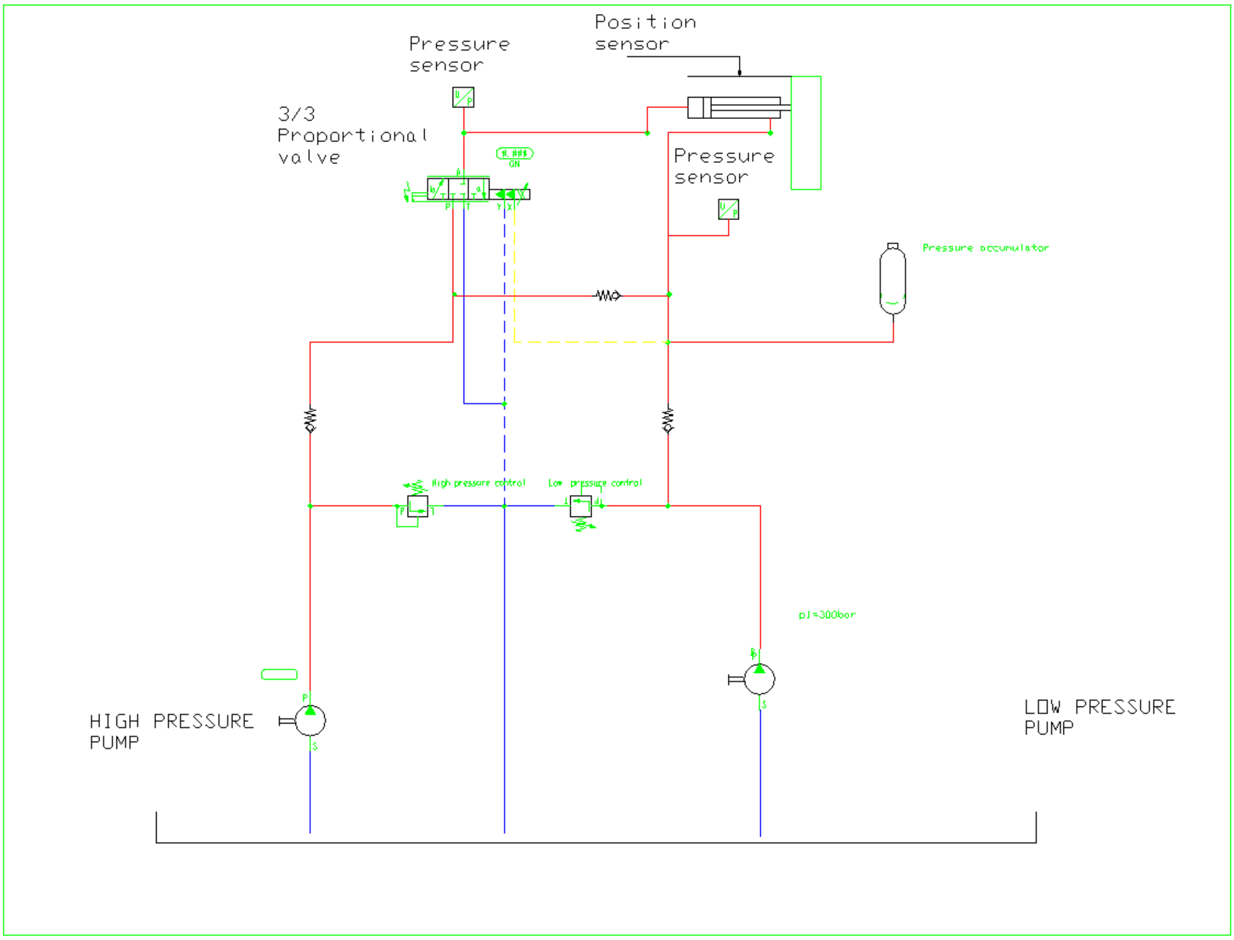

Figure 9 3/3 circuit

the retraction chamber of the cylinder is maintained at constant pressure by the pressure accumulator placed on the low pressure side of the circuit. The cylinder will this way operate against a fixed force.

Advantages of this solution

Circuit simplicity,

3/3 proportional valve are of the shell component that can be easily procured

Disadvantages of this solution

In order to make the system working that valve need a good stabilization of upstream pressure that involves the need to install high pressure manifolds and accumulators. The retraction and the start-up logic will need the installation of more component thus increasing the circuit complexity. Depending on the valve /pump choice high air pressure flux is also required.

All the valves have to be connected to the high pressure feed line manifold thus increasing the parts subject to high pressure load that have also to be tested against burst (typical factor = 4 , 2800 bar)

8.4 4/3 CIRCUIT

This circuit is based on the availability of a 4/3 directional proportional valve. This solution is very similar to the one adopted for the reduced scale testing equipment [R 1]. This technology is well proven . The accuracy achievable with this method is better than +/- 100 microns.

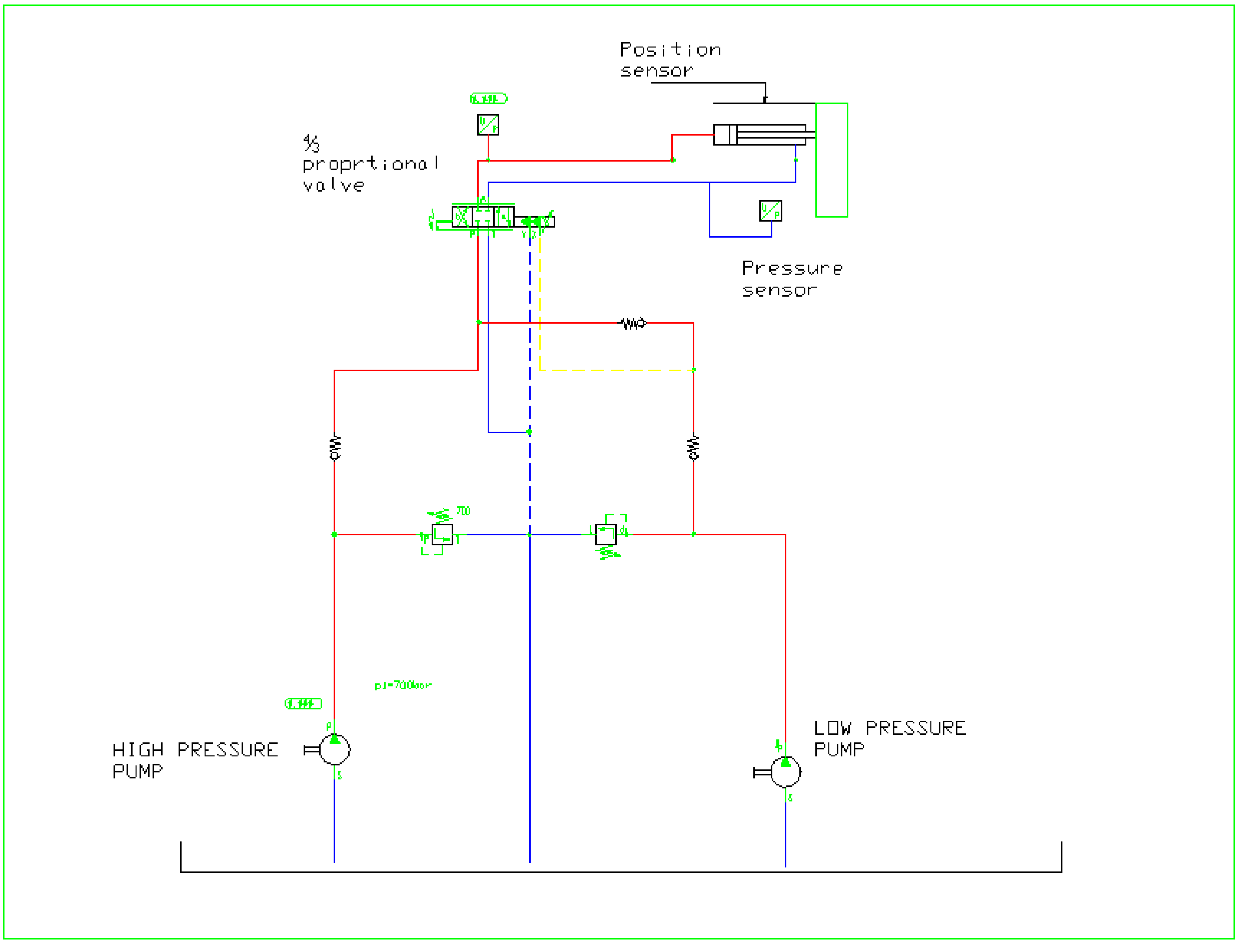

Figure 10 4/3 circuit

Advantages

This kind of circuit is very well known at low pressure (350 bar). No test or specific R&D is needed and very high accuracy are obtainable.

Disadvantages

There is a little experience of this circuit working at 700 bars. The use of high pressure proportional valves is demanding and there are very few manufacturers of such valves.

The valve itself produce a pressure drop of 30-50 Bar meaning that the maximum

Differential pressure in the cylinder chambers will be limited to 650-670 bar with a consequent reduction of the pushing force.

All the valves have to be connected to the high pressure feed line manifold thus increasing the parts subject to high pressure load that have also to be tested against burst (typical factor = 4 , 2800 bar)

8.5 VOLUMETRIC PUMP CONTROL

An alternative solution suitable for the application is based on the use of 36 very small volumetric pumps . Each pump will be directly connected to one cylinder pressure chamber . A calibrated orifice will set the actuator working point.

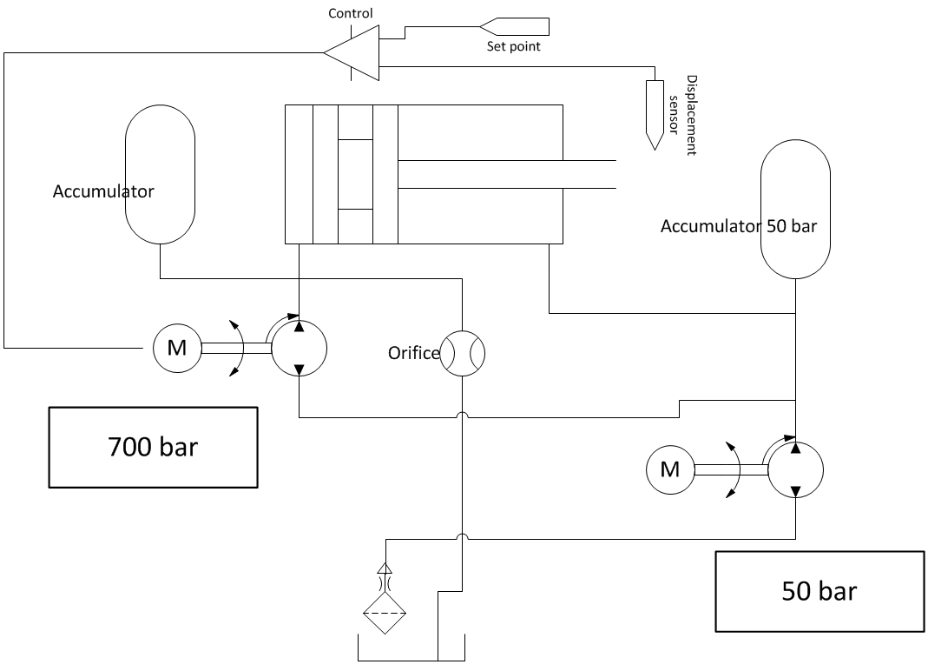

Figure 11 Volumetric control circuit

The displacement sensor signal is feedback to the control unit that controlling the the pump revolutions will implicitly tune the pressure in the pushing chamber. The retraction of the jack is obtained by pushing low pressure fluid in the pull back cylinder chamber. Since the orifice calibration will influence the circuit working point a proportional orifice component has to be used. With a little increasing the circuit complexity it is also conceivable to combine the already presented circuit such to have a low pressure function with a 4/3 standard valve up to 350 bar = 18000 pushing tons to be switched to high force mode in case of full power is needed.

Advantages

The overall facility layout will be greatly simplified .

Due to the reduced size of this pumping unit (typically smaller than 100*50*50 mm) it is possible to install two pumping-motor unit on each double cylinder body.

The part of the facility running high pressure is very limited and sytem can be highly modularized. Each double cylinder body will constitute a full independent hydraulic- electric unit for a neater and safer general layout.

Pumping unit of this type can be rated to pressure as high as 1000 bar, thus making future system upgrading possible.

Disadvantages

The tuning of the orifice needs a little testing before freezing the design . This qualification tests can be executed with smaller off the shelf cylinders rated to work @ 700 bar.

8.6 CONTROL SYSTEM

The control system layout is shown in Figure 12. The test operator controls the machine by means of a Graphical user Interface (GUI). Assuming that the ring under test is already installed and supported by an appropriate support system that Operator will first set up the pressure cut off valve threshold value. This pressure value defines the maximum oil pressure in the circuit. Setting this parameter is very important to guarantee that forces exceeding a specific value mighjt be delivered by the actuators. Once this max pressure is set , the operator will set the radial motion step .And after checking that all the sensitive machine parameters are ok and no alarm or interlock is activated he will allow the machine to expand by the radial motion step. A typical value for this is between 0.1 and 0.5 mm. According the request the actuator will move radially and pressure will rais up in chambers according to the PCR elasticity. A simplified and effective gui will be presented summarizing all the relevant machine parameters and in particular actuator strokes and forces deliverd. The latter will be calculated taking into account piston effective areas and differential pressure.

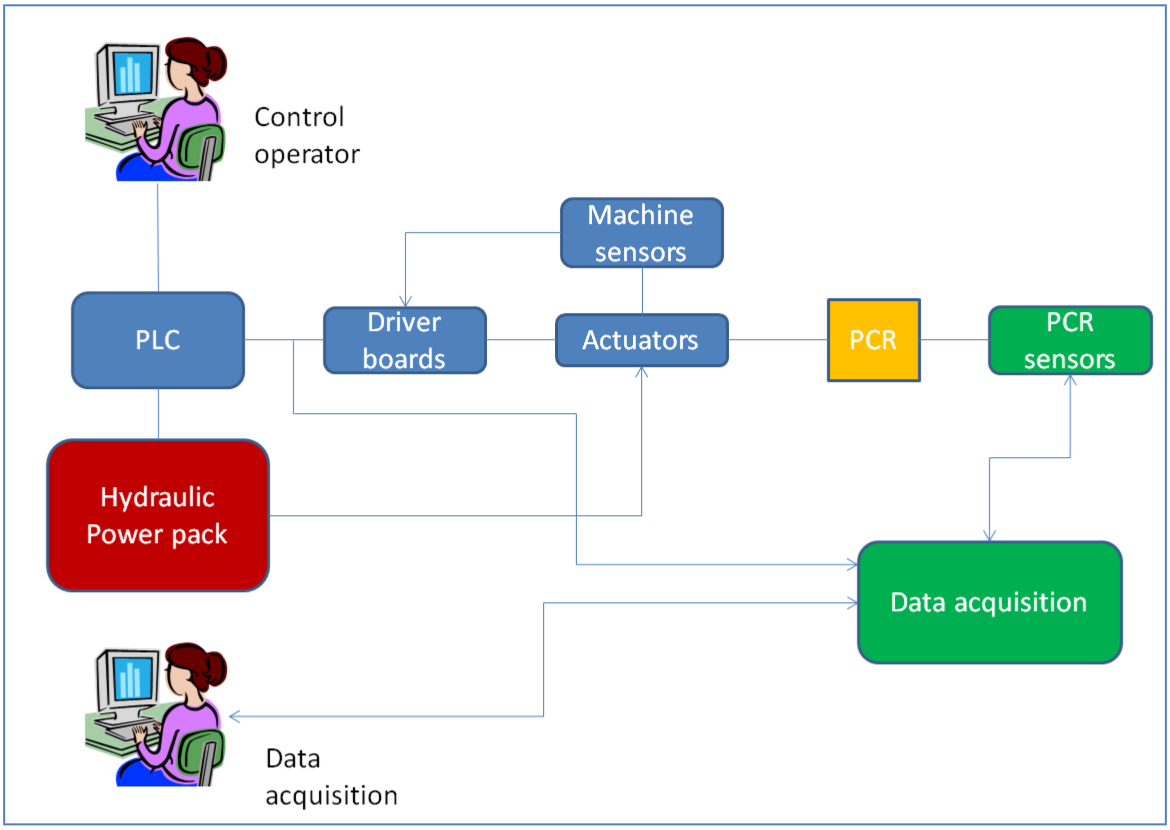

Figure 12 Control layout

During the operations a full independent data acquisition stem will run in the background. The data acquisition system will collect sensor and machine parameters from the PLC controller and signals generated by additional sensors installed on the PCR. Among the others it is worth to mention that the following parameters will be continuously sampled during the tests.

- Circuit pressures
- Cylinder pressures
- Cylinder strokes
- Actuator loads
- Machine setting parameters
- PCR strain
- Spreader displacement in 4 locations for each spreader

The above parameters complemented with test parameters and description will be saved into a structured data base for post-test elaboration.

Sampling time will be variable such as to increase the sampling rate from 2 Hertz to 1 Hertz in proximity of the PCR failure.

Complementary to the Data acquisition sytem the geometry of the machine and the actual deformation of the ring will be real time monitored by optical instrumentation. It is indeed foreseen to use a laser Tracking technology to define the machine " home" configuration an a real time camera system to asses the ring deformed shape. Four fiducial supports will be installed on each spreader such as to allow the detail measurement of the spreader movement and orientation.

Photogrammetry targets will be instead slicked on the PCR surface in many location (more than 500) . This will produce a real time deformation grid that can be also very useful to determine internal ring stress levels by means of the real time inverse convolution method.

9 MACHINE PARAMETER SUMMARY

Table 1 reports the PCRTM overall dimensionala and performance parameters

Parameter	Value	Comment
Radial built	6 m	Approximate diameter
Height	2 m	
Overall weight	200 ton	Including concrete
Heaviest part	50 ton	Without concrete
Concrete cast weight	30 ton	Reinforced cast
Number of actuators	36	
Maximum thrust per actuator	1000 ton	
Maximum operating pressure	700 bar	
Maximum actuating speed	1mm/min	extension
Maximum return speed	10 mm/min	retraction
Maximum cylinder	75 mm	

stroke		
Installation free play	5mm	on the radius
Maximum ring expansion	70 mm	
Maximum displacement ripple	+/- 0.1 mm	Actuator to actuator value
Minimum actuating step	0.1 mm	radially
Duty cycle	10%	
Type of machine	Hydraulic synchronized	
Test nominal temperature	20 C	Room conditions
Hydraulic fluid max temp	150 C	
Type of circuit	sealed	To avoid contamination
Type of control	displacement closed loop	
Control	each cylinder	Individual
Data acquisition system frequency	2 Hertz to 1 KHertz	Parameter sensitive
Electrical power	15 KW	Continuous operation

Table 1 PCRTM main parameters

10 STRESS ANALISYS

A nonlinear stress analysis calculation has been carried out to assess general stress levels in the main structural component of the machine.

All the contact surface s between component have been properly modelled and simulated . Materials behaviour has been considered elastic isotropic . Fluid action has been simulated by applying 70 Mpa of pressure to the relevant part of the cylinders. The load case exanimated is the maximum load equivalent to 200 ton of radial force on each spreader .

More details about the stress calculation can be found in [R 1]

10.1 CONCRETE AND CENTRAL STRUCTURE

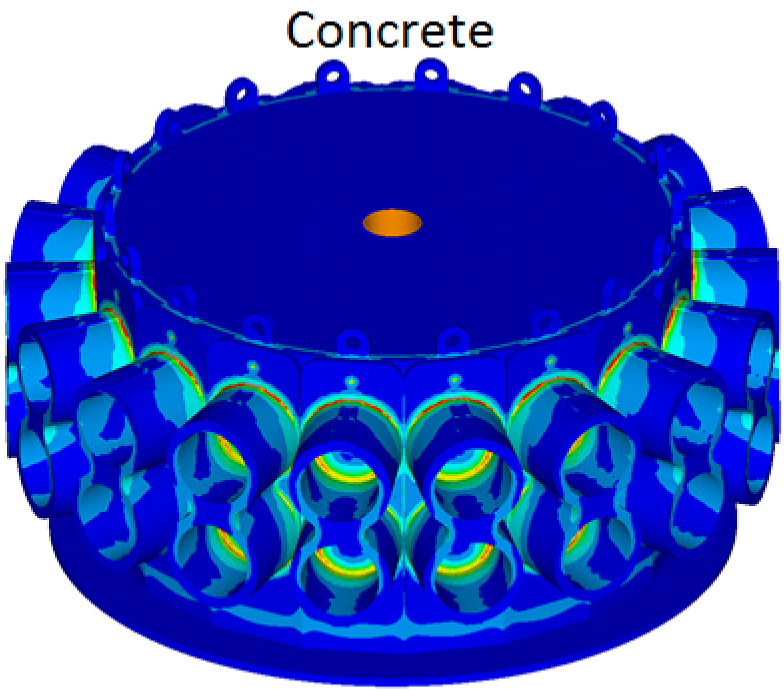

Figure 13 Central structure model

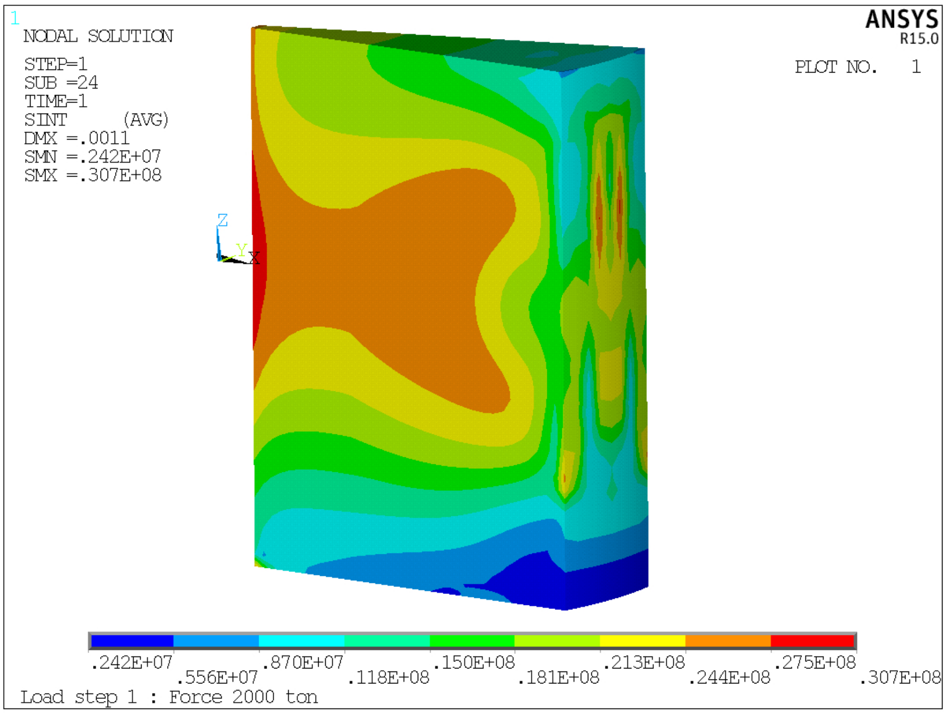

Figure 14 Concrete stress intensity [Pa]

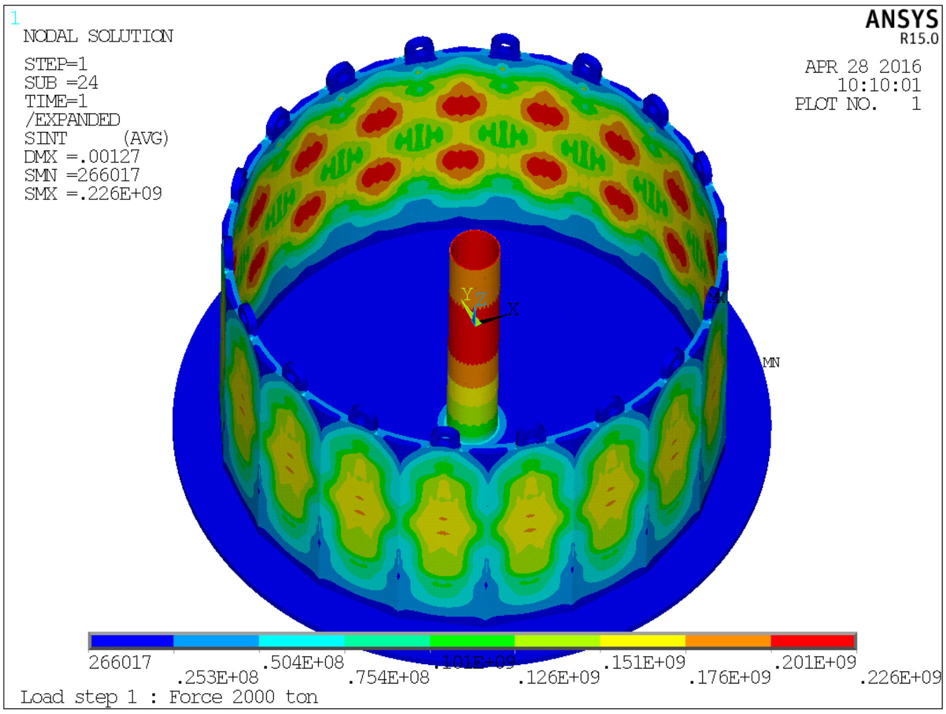

Figure 15 Central column stress intensity [Pa]

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10.2 HYDRAULIC CYLINDERS

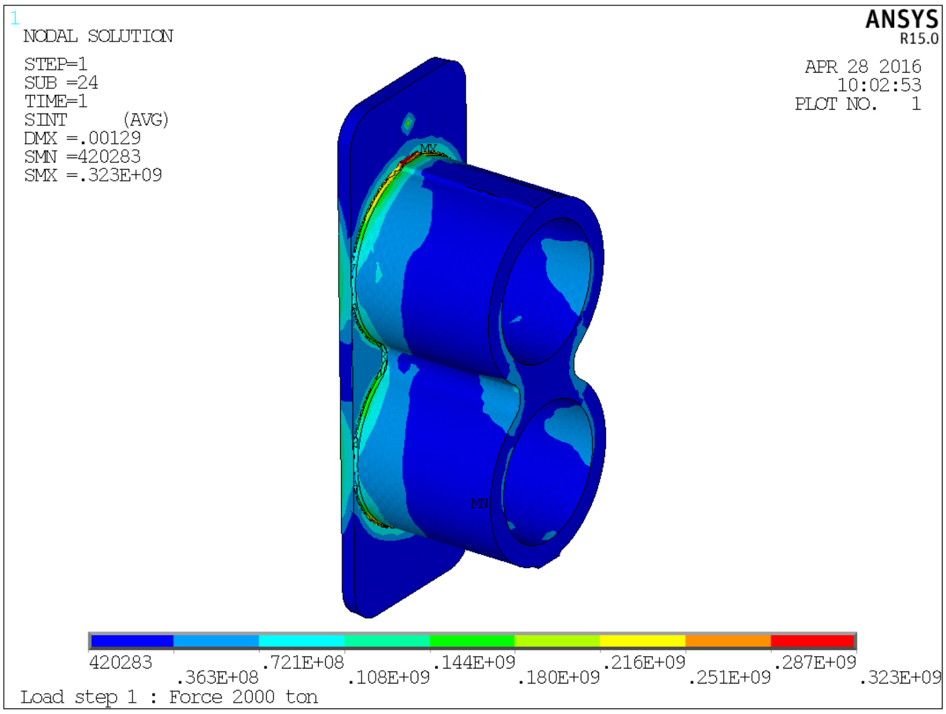

Figure 16 Cylinder stress intensity [Pa]

10.3 SPREADER AND CUSHION

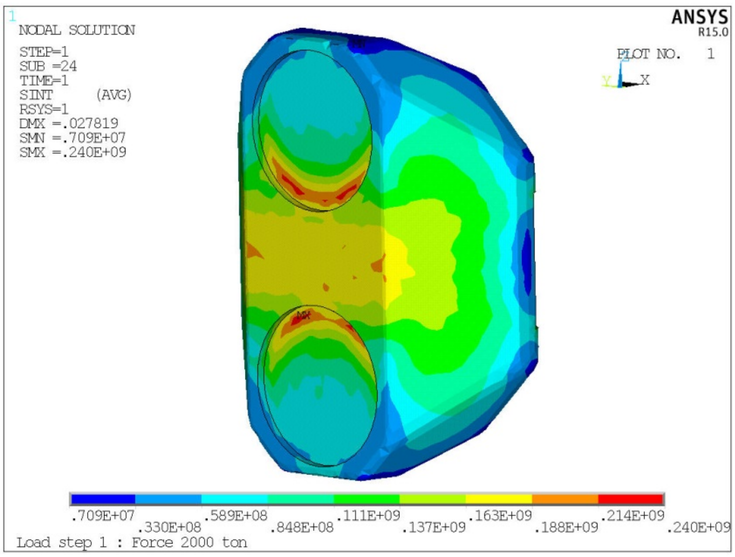

Figure 17 Spreader stress intensity

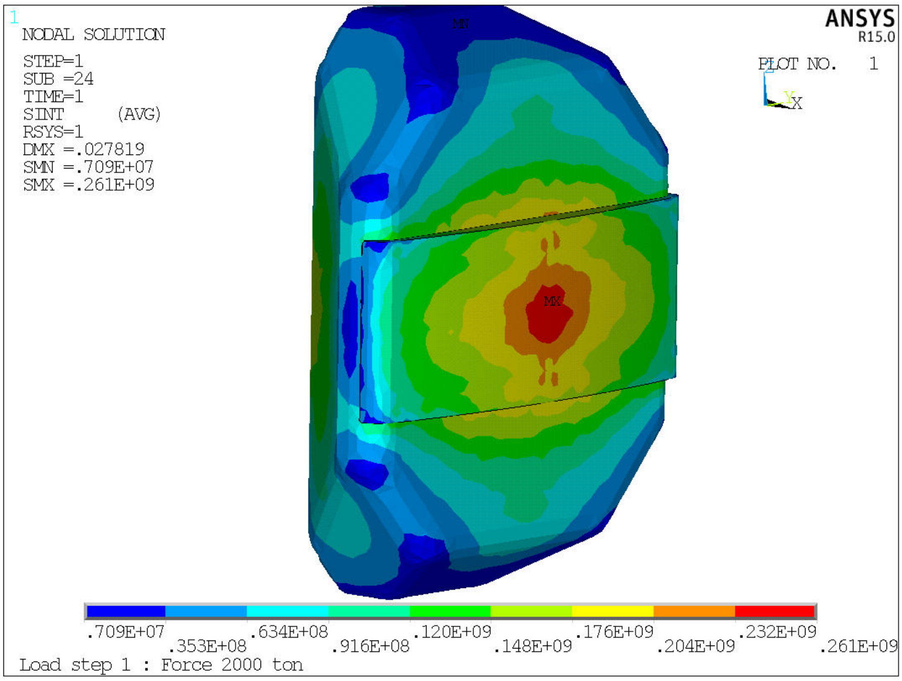

Figure 18 cushion stress intensity [Pa]

11 CONCLUSION

The conceptual design of the testing machine confirme the machine feasibility

Design tuning is needed to improve the loads transmission between the actuatin rod and the spreade and the stress distribution at the cushion/ring interface