8TH AUSTRALIAN SMALL BRIDGES CONFERENCE - 2017

Discussion Topic:-

Computer Controlled Synchronous Jacking for the Maintenance of Bridges

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Synopsis

This paper provides a detailed analysis of the options available when it comes to precisely lifting large heavy structures such as bridges using hydraulics.

It looks at what options are available in the market place, how each system works, the input functions that can be controlled during a lift and the parameters that can be set to stop a lift if those values are out of tolerance.

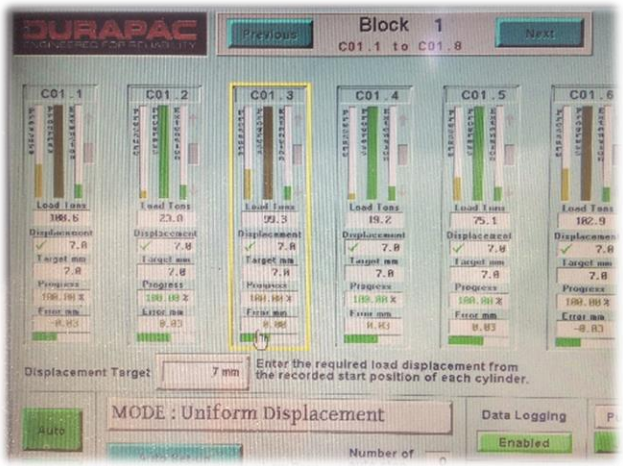
Some of the other variables that need to be considered when planning a lift include lateral displacement, side loading on cylinders and safety features such as check valves and mechanical locking collar cylinders which all form part of developing a safe and effective hydraulic system.

It will review a Computer Controlled Synchronous Jacking System and what realistic tolerances / accuracy is achievable during heavy lifts using hydraulic cylinders and some of the features and benefits of a Synchronous Systems including some examples of heavy lifts conducted across Australia.

Introduction

This presentation is intended to provide a detailed analysis of the complete process of lifting a large structure such as a bridge using high pressure hydraulics to precisely lift and control the movement of the structure without inducing any additional unnecessary stresses.

We will cover:-



- Project Planning
  - Jacking Locations
- Equipment Capability
  - Components that make up a Hydraulic System
  - Manual Hydraulic System
  - Split Flow System
  - Computer Controlled Synchronous Jacking System
  - Multiple Computer Controlled Synchronous Jacking Systems
  - Accuracy of Each System
  - Types of Cylinders

Introduction - Continued

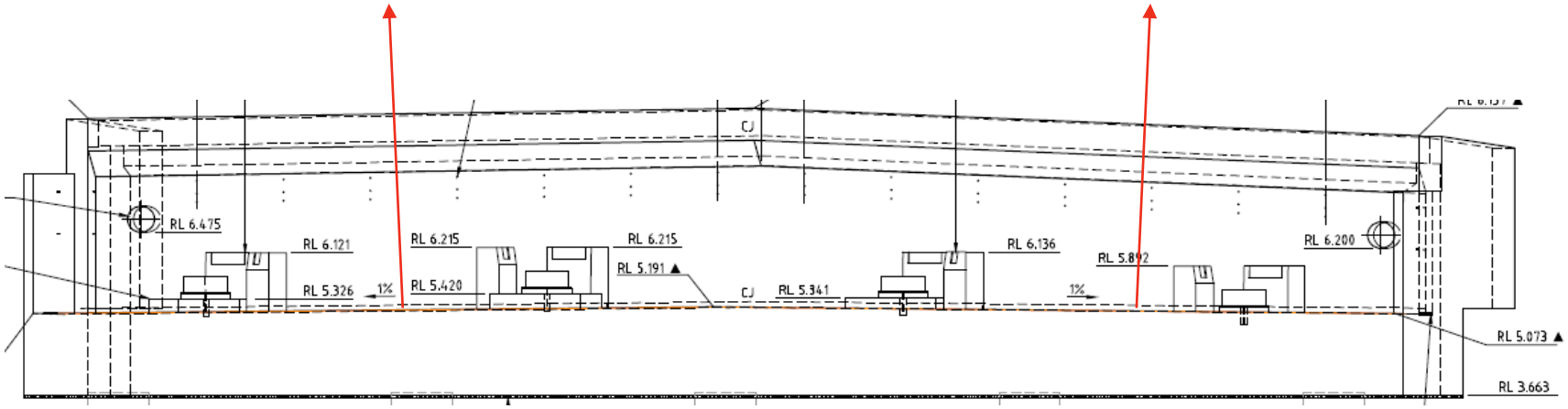
- Lift Design
  - Longitudinal and Lateral Restraint
  - Bearing Pressure
  - Cylinder Selection
  - Cylinder Set Up and Orientation – Side Loading
  - Target Height of Lift
  - Allowable differential between Jacking Points
  - Actual Tonnage per Jacking Point
  - Input Alarm Parameters for Computer Controlled Synchronous Lifting
- Conducting the Lift
  - Stages in a Lift
  - Monitoring
- Analysis of the Process
  - Recorded Data Files

Project Planning

Jacking Locations

Often jacking locations form the biggest issue when planning a lift. Some of the major factors that need to be considers are:-

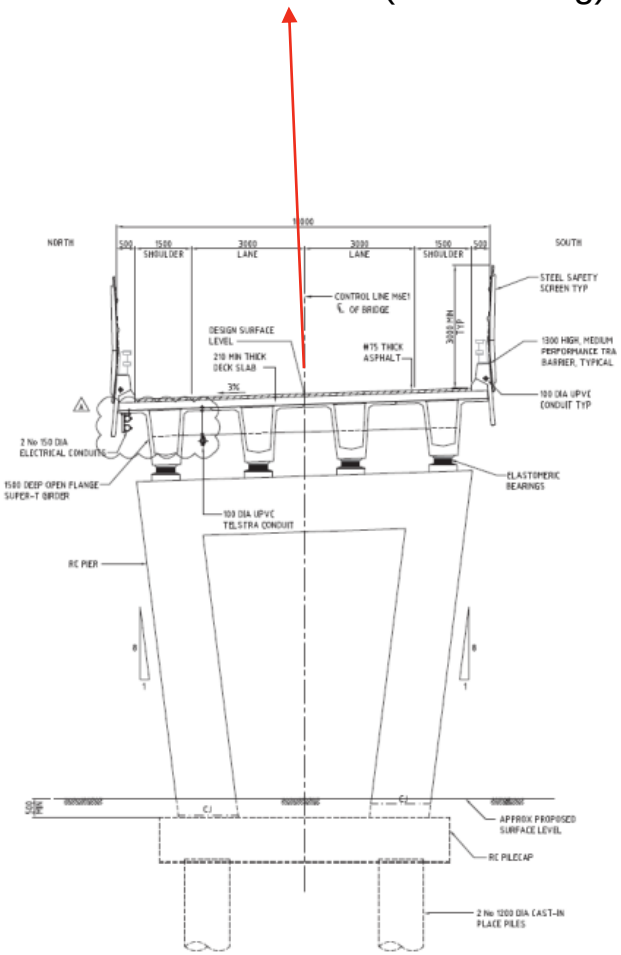
- Flat level jacking pad to jack in the vertical plane
  - Induce stress into the structure when jacking if cross fall from the centre line is in two different planes

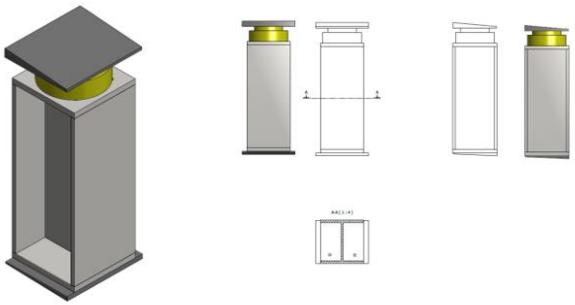


Project Planning

Jacking Locations

- Induce stress (side loading) into the cylinder if not in the vertical plane

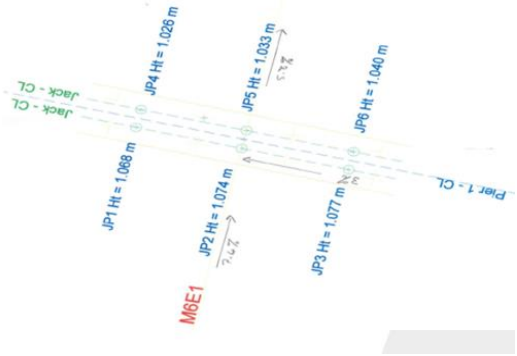




Cross / Longitudinal Fall

Bridge has significant Cross & Longitudinal Fall which needed consideration

- Needed to bring the stools into the vertical plain – wedge plates
- Conduct the lift in the vertical plain
- Lateral restraint to be considered



Project Planning

Jacking Locations

- Sufficient bearing surface to not exceed the concretes compressive strength
- Cylinder selection and physical dimensions
  - Outside diameter
  - Cylinder weight – up to 74 kg for a RSLC2502 cylinder
  - Cylinder collapsed height vs available stroke
- Head room to fit the correct cylinder
  - Height of lift
- Jacking stands and packing

Equipment Capability

Components that make up a Hydraulic System

- In an effort to simplify hydraulic jacking we will break the system down into six basic component groups as shown.

1. Cylinders

2. Pumps

3. Hoses

4. Manifolds

5. Valves

6. Gauges

Basic Hydraulic System

- There are 3 critical components that must be used in a hydraulic system – Pump, Hose and Cylinder.

- When introducing a sync system to a complex hydraulic system, there are many factors that must be considered to ensure a successful lift.

Equipment Capability

Manual Hydraulic System

- A basic hydraulic system which has a pump, hose and cylinder is :-
  - Cheapest to procure
  - Easiest to operate
  - Has the least amount of control
    - Large variation between lifting points depending on load distribution
  - Information relayed via manual measurements and readings
    - No formal recording throughout the entire lift
    - Open to interpretation and human error
  - Increases in complexity when operating multiple cylinder
  - Load transfer between cylinders is very hard to control
  - Induce unnecessary stress into the structure
  - Very hard to control lifting and lowering in a uniform manner

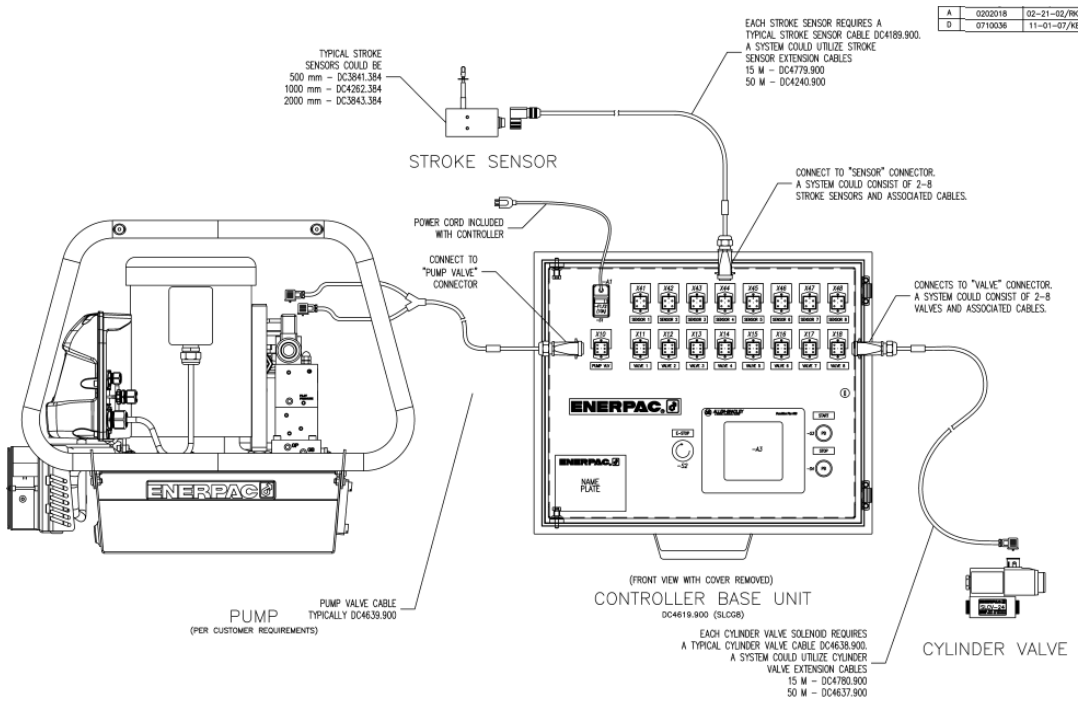
Equipment Capability

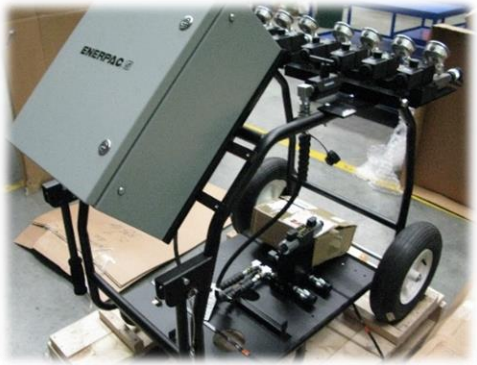
Split Flow Hydraulic System

- Often called a synchronous system, a split flow pump delivers an equal amount of oil to each of the outlets to achieve a semi synchronous lift but:-

  - Limited to the number of ports on the pump (4 port)
  - All cylinders must have the same effective area (capacity)
  - Accuracy is dependant on the load distribution at the jacking points
  - There is no displacement feedback, data logging or monitoring
  - The system does not change the displacement of each cylinder unless manually controlled via valves
  - Same accuracy as a manual system when lowering

BASIC Synchronous Jacking Systems

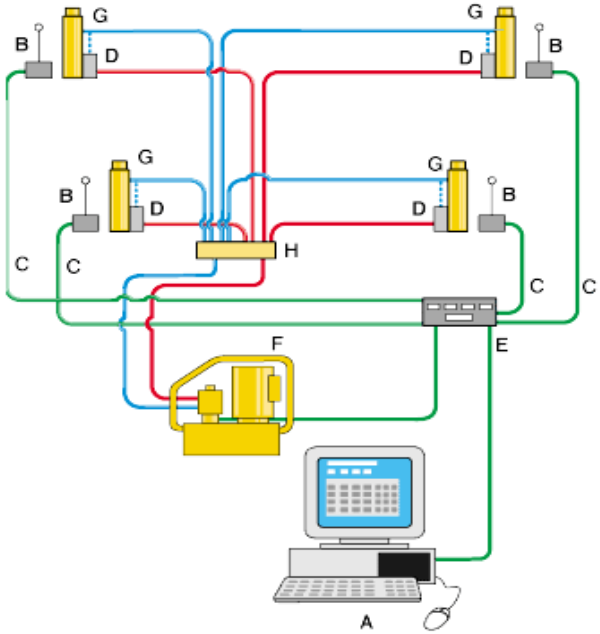




Equipment Capability

- Components that make up a Computer Controlled Synchronised Jacking System

A Computer
B Reader
C Hoses
D non return valve
E Control module
F Pump
G Cylinder
H Manifold

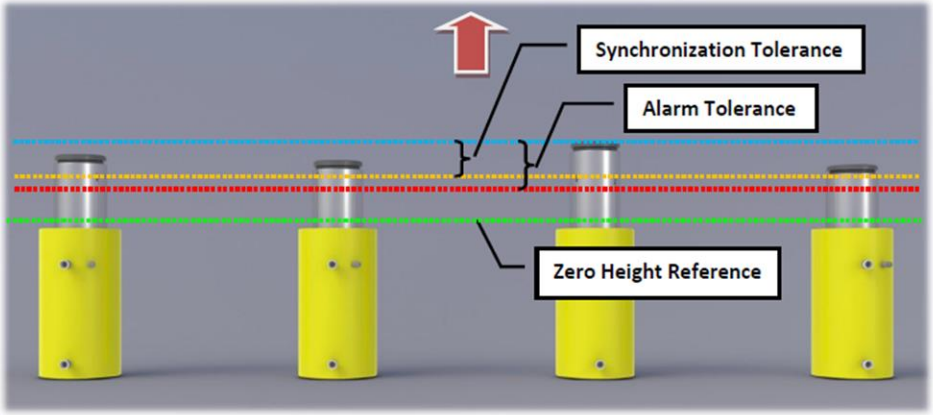


- Synchronous system eliminates the need for manually operating flow control valves.
- Allows full record ability of operations
- Odd tonnage cylinders can be calibrated into system
- Ideal for large structures such as slabs, bridges and large machines

Equipment Capability

Computer Controlled Synchronous Jacking System

- Synchronisation is the control of oil to each cylinder to ensure the stroke of each ram is within set tolerance to each of the other cylinders in the hydraulic system. This is achieved using sequentially controlled valves from an initial datum point.



Parameters involved in a synchronized lifting operation

- It relies on displacement data received from the cylinder location to adjust the flow of oil to that point during the lift.

Equipment Capability

Computer Controlled Synchronous Jacking System

- Synchronisation is achieved by:-

- Direct measurement of load displacement at each lifting point
- Direct measurement of cylinder displacement at each lifting point
- Measurement and control of pressure and hence load or force at each lifting point

- The benefits of this technology include:-

- Multiple systems can be configured in a Master / Slave arrangement
- High levels of accuracy and precision in displacement control (less than 1mm)

Equipment Capability

Computer Controlled Synchronous Jacking System

- Specifically we will look at the DSM Series Durapac SyncMaster computer controlled synchronous jacking system – DSM4038 and its features and benefits.
- This unit has very similar features to other units in the market and some defining functionality that is unique to the Durapac brand.
- Importantly it is designed and manufactured in Australia with after market service and technical support from a local provider

Equipment Capability

Computer Controlled Synchronous Jacking System

Each unit has different specifications including:-

- Motor / Pump size
- Flow Rates
- Number of outlets
- Reservoir Capacity
- Valving Configuration
- PLC / Computer Configuration

Model Number	Flow Rate (Lpm)	Pressure Rating (bar)	Motor (kW)	Amps	No. of Outlets	Useable Oil Capacity (L)
DSM1554	0.95	700	1.5	8.3	4	50
DSM1558	0.95	700	1.5	8.3	8	50
DSM3054	1.75	700	3.0	6.3	4	50
DSM3018	1.75	700	3.0	6.3	8	100
DSM4014	3.0	700	4.0	8.85	4	100
DSM4018	3.0	700	4.0	8.85	8	100
DSM5514	3.97	700	5.5	8.85	4	100
DSM5518	3.97	700	5.5	8.85	8	100
DSM7538	3.97	700	7.5	8.85	8	100

Which control the lift and ability to achieve various outcomes from the one control centre based on the design functionality of the unit and its software.

Equipment Capability

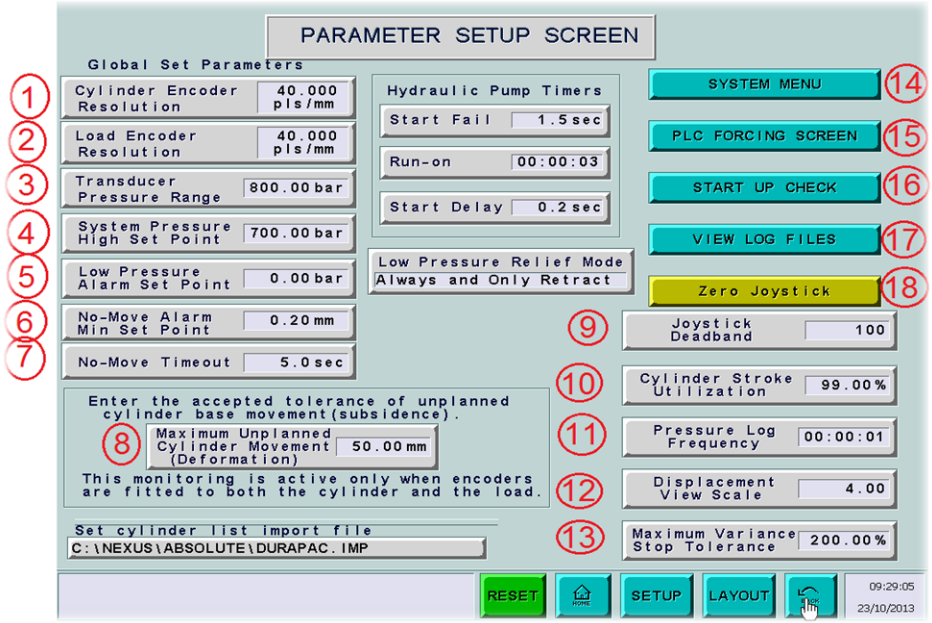
Computer Controlled Synchronous Jacking System

- Data logging of displacement and pressure
- Different lift modes, including tilting, uniform displacement, pressure preload
- Measurement and control of Centre of Gravity
- Control of pump speed to suit various cylinders and required lifting speeds

- During the lifting process all cylinders will actuate to reach a target height from information relayed from the stroke sensors attached to the load. The load can be unevenly distributed and with various capacity cylinders but the synchronous jacking system will still control the lift process within defined parameters.

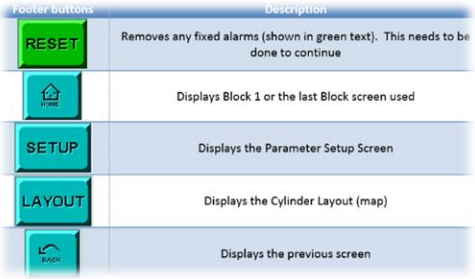
SyncMaster Features

- General Operation Modes:-

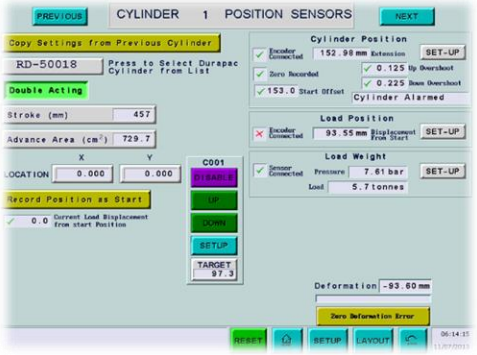


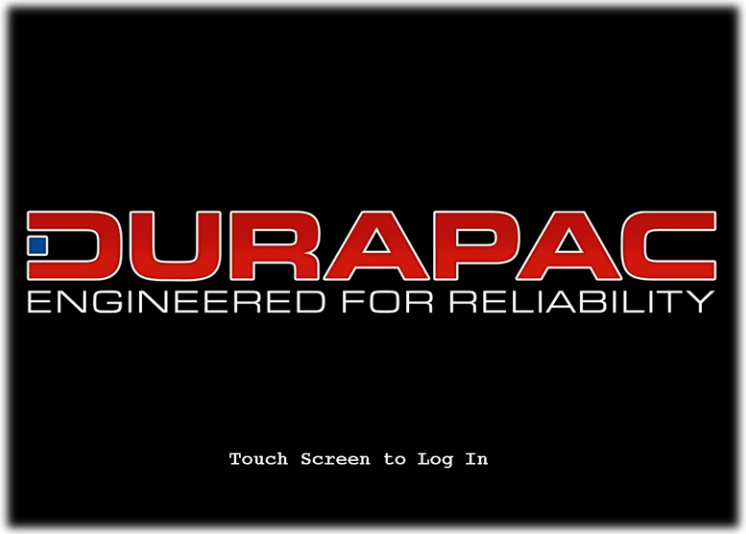
- ✓ Joystick Manual
- ✓ Uniform Displacement
- ✓ 2 Point Displacement
- ✓ 3 Point Displacement
- ✓ Stage Load Control
- ✓ Return All Cylinders
- ✓ Pre-Load All Cylinders

SyncMaster Lift Parameters

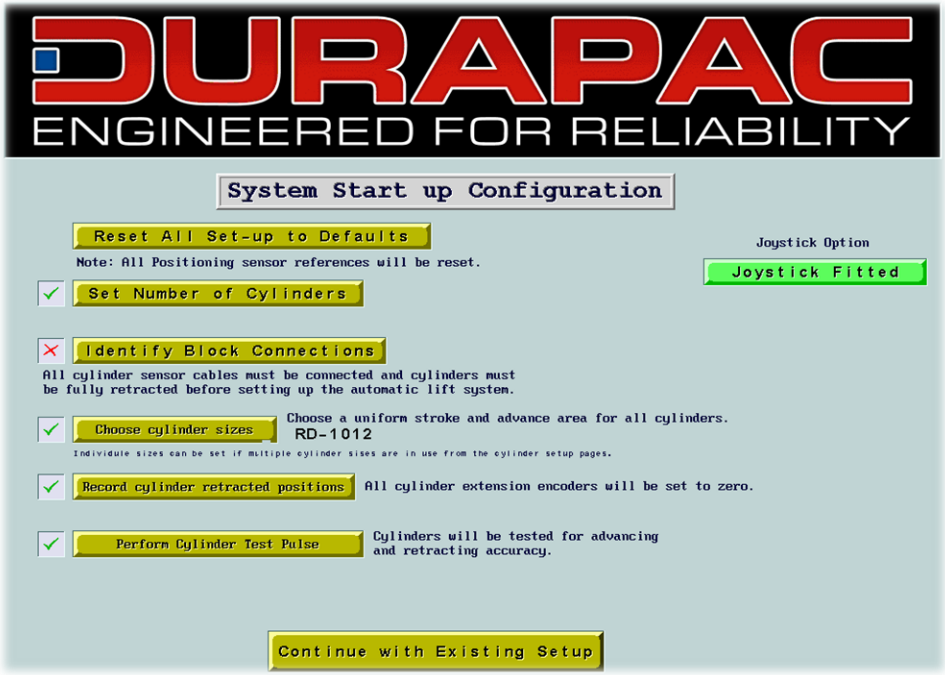


- Simple touch screen user interface
- Control parameters include alarms to monitor -
  - Maximum / Minimum Cylinder Load
  - Centre of Gravity Functionality
  - Load versus Cylinder movement
  - Maximum Total Load
  - Stop Tolerance – Maximum allowable deviation between cylinders and load
  - Work Tolerance – ≥ 0.1 mm deviation between jacking points (depending on the structural properties)



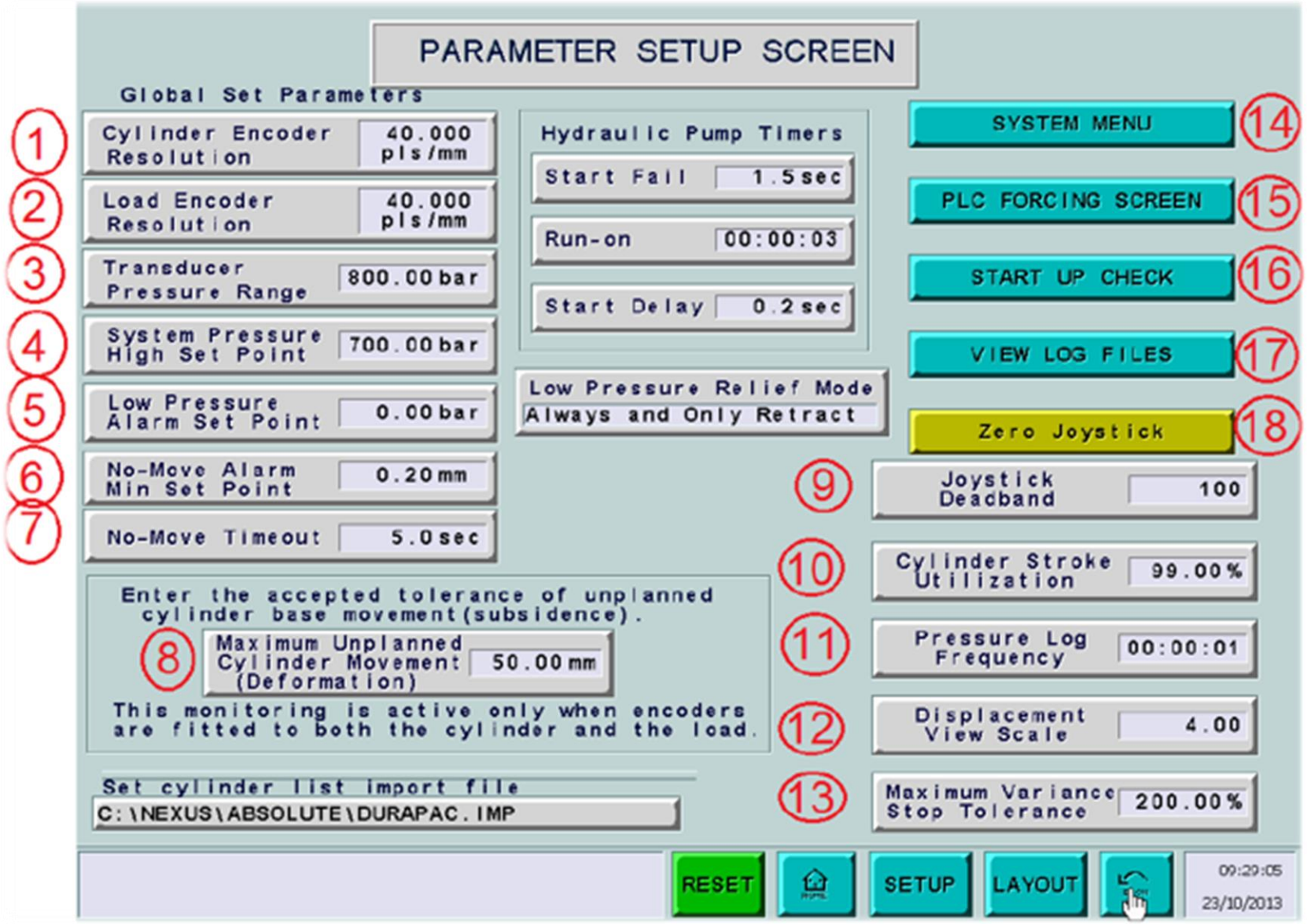


- **Start Up screen**

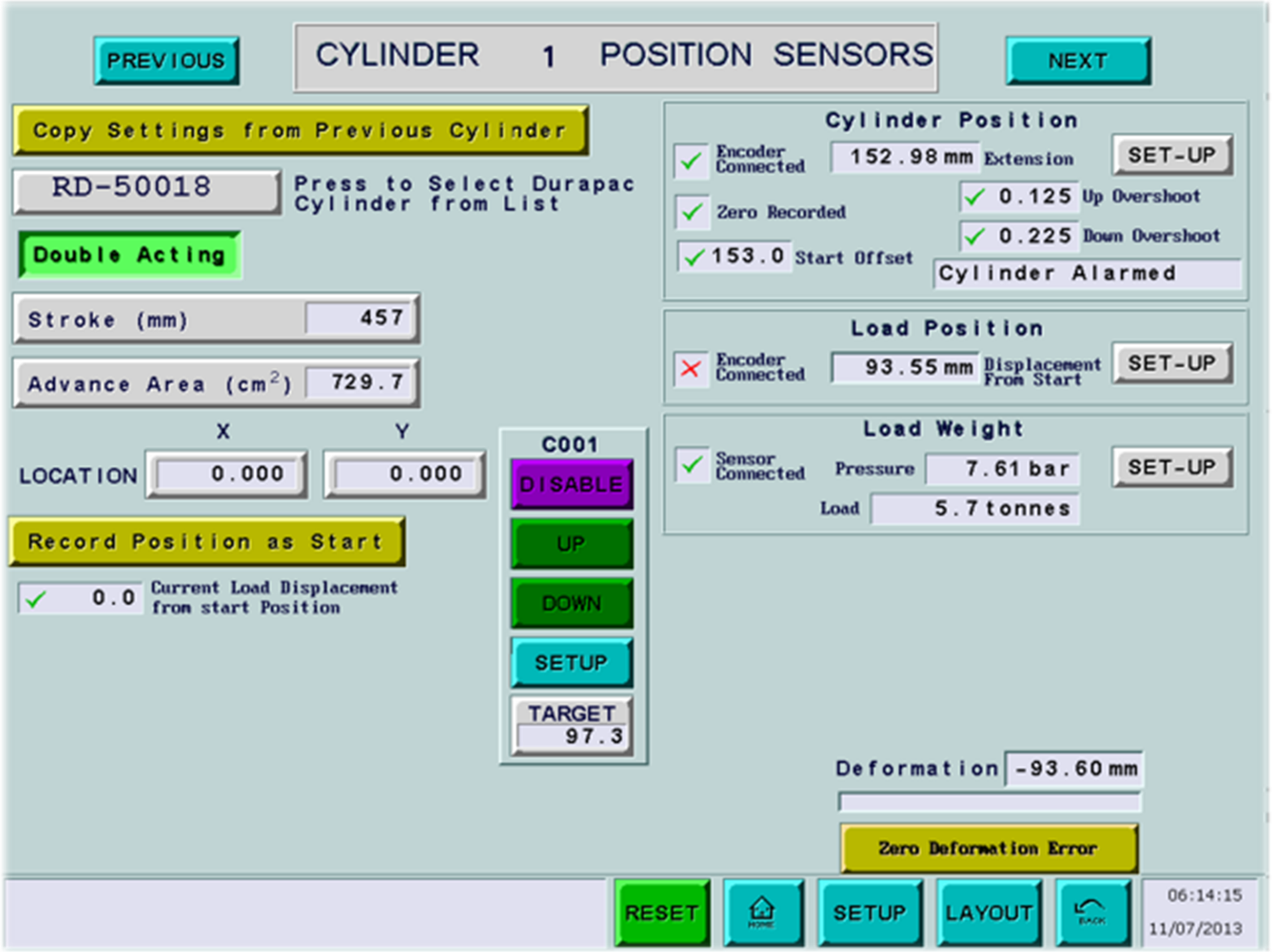


- **Configuration Screen**

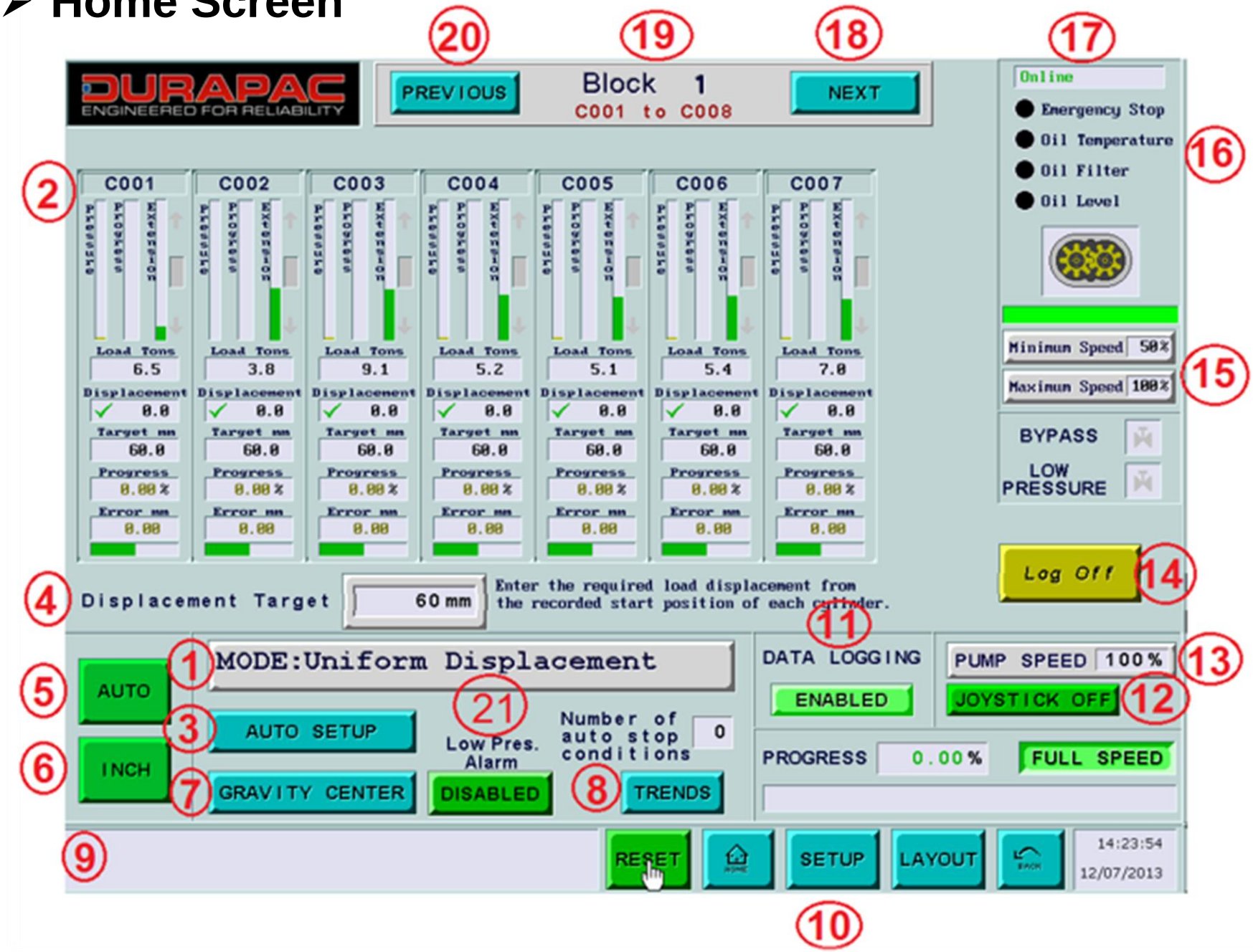
➢ Control Parameters



➢ Cylinder information



➢ Home Screen


DURAPAC
ENGINEERED FOR RELIABILITY
PREVIOUS
Block 1
C001 to C008
NEXT
Online
Emergency Stop
Oil Temperature
Oil Filter
Oil Level
C001
C002
C003
C004
C005
C006
C007
Pressure
Progress
Extension
Load Tons
6.5
3.8
9.1
5.2
5.1
5.4
7.0
Displacement
0.0
Target mm
60.0
Progress
0.00%
Error mm
0.00
Minimum Speed 50%
Maximum Speed 100%
BYPASS
LOW PRESSURE
Log Off
Displacement Target
60 mm
Enter the required load displacement from the recorded start position of each cylinder.
MODE:Uniform Displacement
AUTO
INCH
AUTO SETUP
GRAVITY CENTER
Low Pres. Alarm
DISABLED
Number of auto stop conditions
0
TRENDS
DATA LOGGING
ENABLED
PUMP SPEED 100%
JOYSTICK OFF
PROGRESS
0.00%
FULL SPEED
RESET
SETUP
LAYOUT
14:23:54
12/07/2013
1
2
3
4
5
6
7
8
9
10
11
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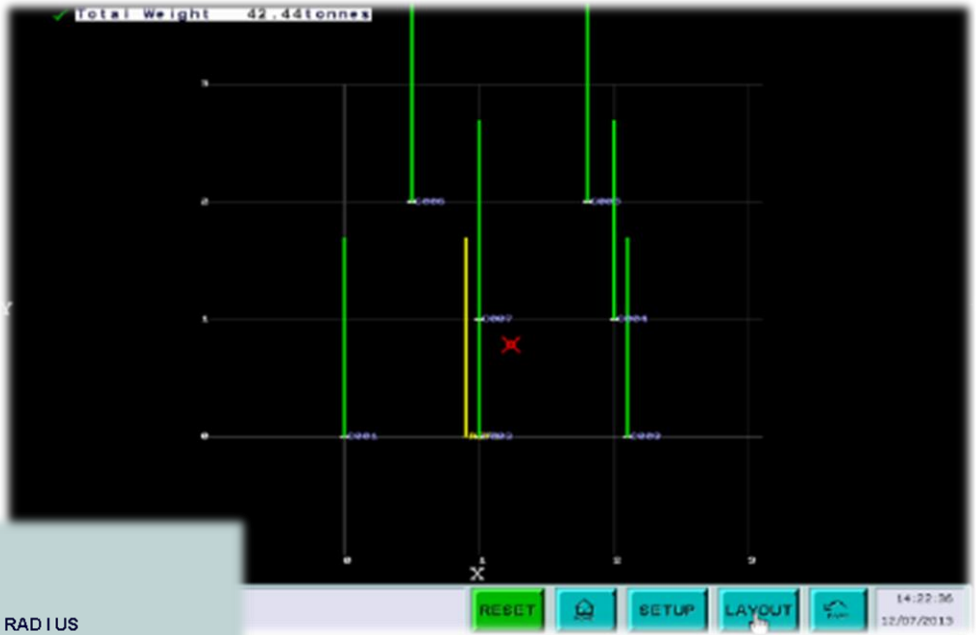
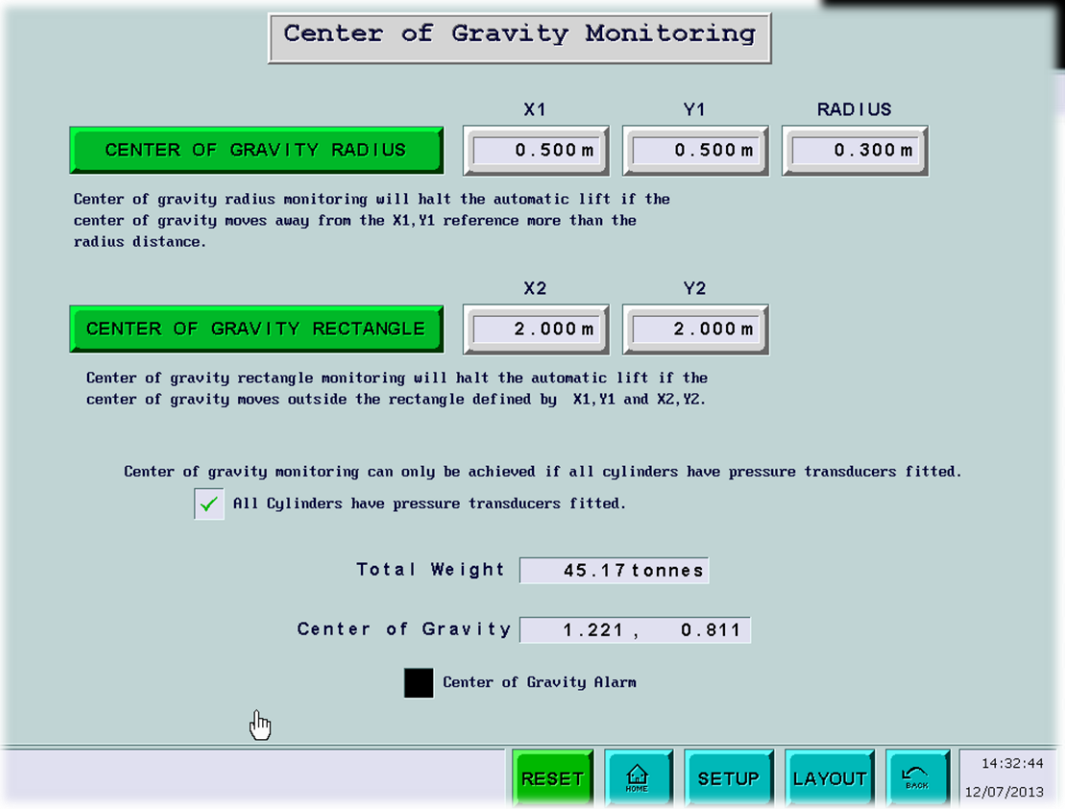
20
21

➢ Centre of Gravity

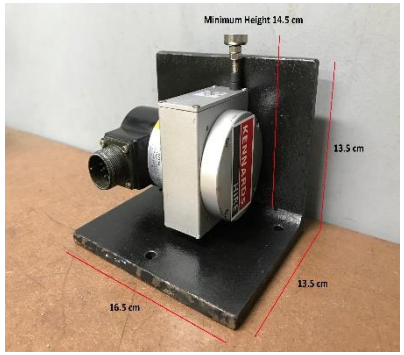




- Set up cylinder locations using X-Y co-ordinates
- Ability to set a circular or rectangular fence around the COG
- The system will stop the lift if the COG goes outside the set parameters

Equipment Capability

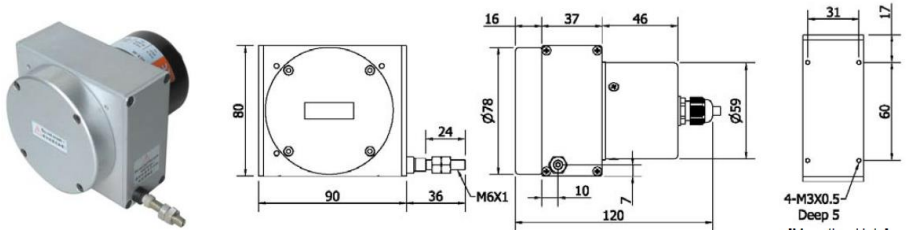
Accuracy and Calibration of Hydraulic Jacking Systems



- Accuracy is dependant on the information relayed from the draw wire encoders to the system and the tolerances that they can achieve.

HONTKO

HLS-M *LINEAR WIRE ENCODER*



ELECTRICAL SPEC.

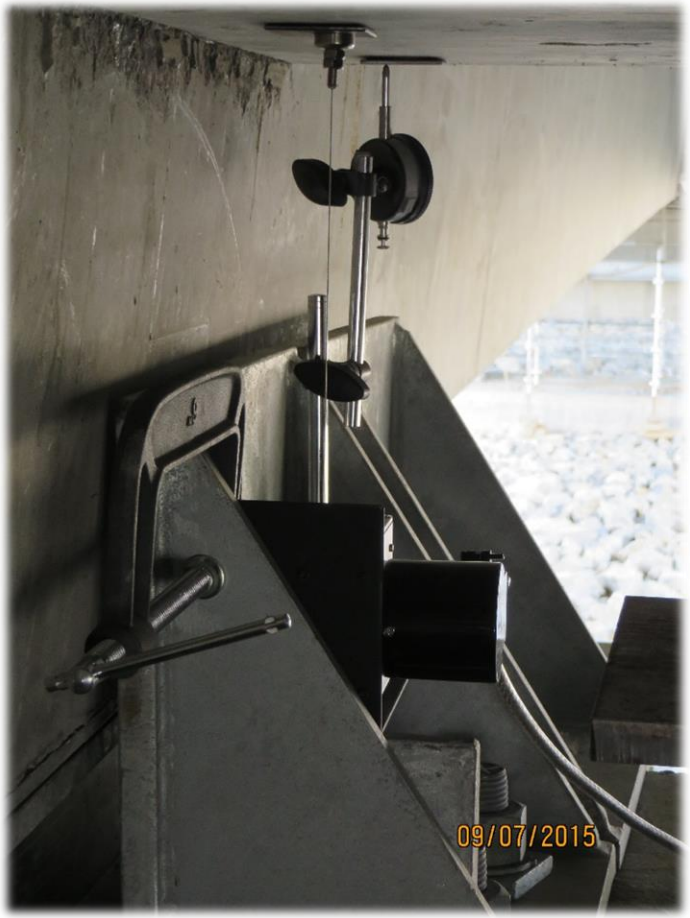
Detection System	Incremental 增量型
Output Wave 輸出波形	Square Wave 方波
Stroke (mm) 量測行程	2000, 3000, 5000
Standard Resolution (mm/pulse) 解析	0.5, 0.1, *0.05 mm/pulse (*0.05 mm/pulse only for stroke: 2000 mm)
Accuracy 精度	±0.05% FS, ±1 count
Output Phase 輸出相	AB phase or ABZ phase
Electronics 電路特性	NPN Voltage, NPN Open Collector, Push Pull or Line Driver
Power Supply 供應電源	DC 8~26V, DC 5V fixed
Current Consumption 消耗電流	≤ 60 mA
Output Capacity 輸出容量	Sync. Current: 20 mA, Residual Voltage: 0.5V or less
Max. Response 最大響應頻率	10K Hz ~ 50K Hz
Phase Different 相位差	A, B phase different 90°±45° (T/4±T/8), Z phase T±T/2
Wave Form Rise / Fall 波形上下時間	2 μs or less
Polarity 極性保護	Against Reverse Protection (not with DC 5V)

Equipment Capability

Accuracy and Calibration of Hydraulic Jacking Systems

- The accuracy of these encodes is +/- 0.05% Full Scale which means at full extension of 1000 mm the accuracy of the reader is 0.5 mm.

- Typical accuracies of a synchronous jacking lift can be down to 0.5 mm across all jacking but is dependant on the set up of the hydraulic system and to structural characteristics of the load.



Equipment Capability

Accuracy and Calibration of Hydraulic Jacking Systems

- Input sources to conduct a lift using the SyncMaster jacking system include:-
  - Pressure Transducers
  - Stroke Sensors / Encoders

- Each of these units can be calibrated and their input signal measured but in relation to the complete hydraulic system but their influence on the accuracy of the lift is negligible – less than 0.1 mm.

- Often customers request to have other components such as cylinders calibrated but there is no adjustment on the cylinder apart from the manufacturers tolerances for cross sectional area and cylinder seal frictional losses which will influence the cylinders performance compared to theoretical.

Equipment Capability

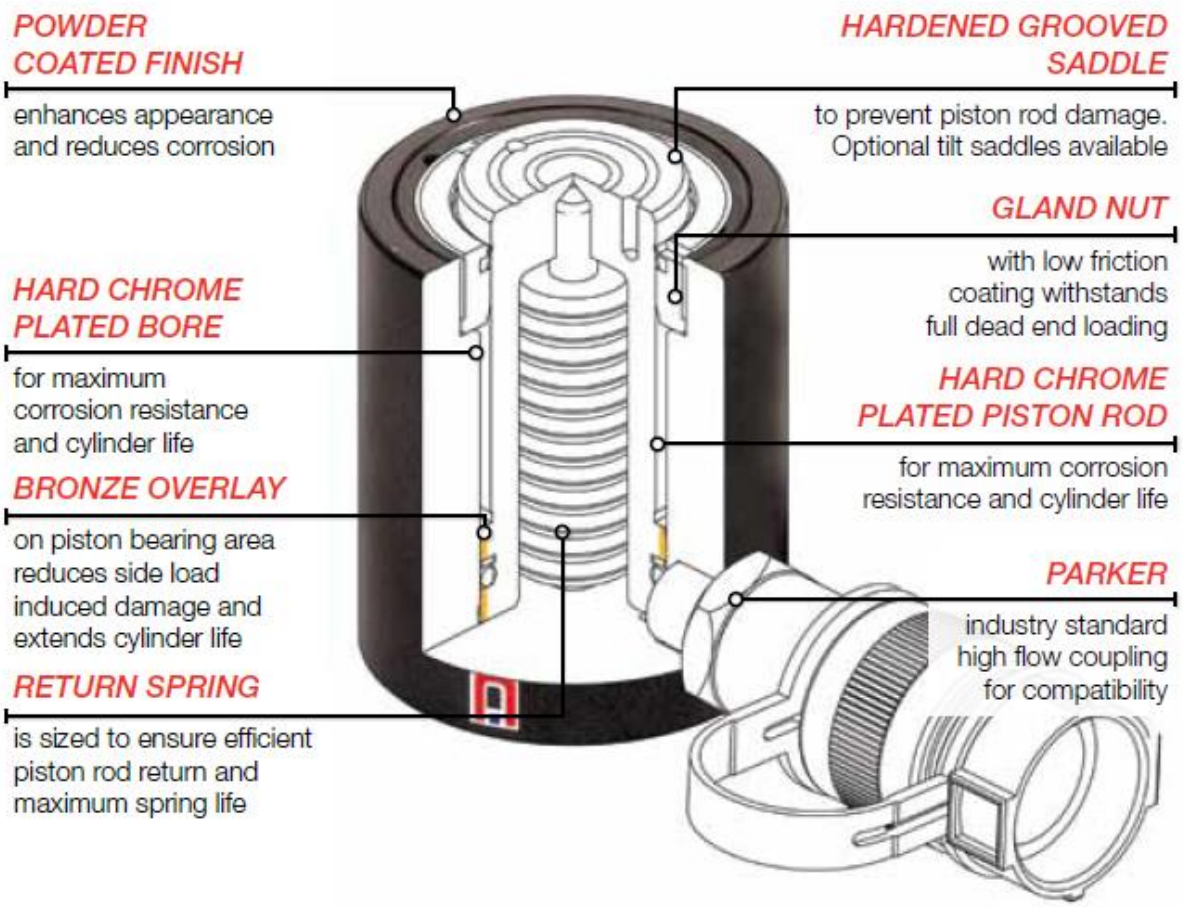
Types of Hydraulic Cylinders

- The cylinder forms the basis of any hydraulic jacking system with all other components supporting this one piece of apparatus.
- The size and type of cylinder used in the circuit is generally dictated by the particular task at hand. Whether it be a requirement for exceptionally large lift capacities, an awkward unbalanced shape or even a particular jacking requirement calling for a jack to fit into a restricted space or even an item needing to be lifted a large distance in a controlled manner of lifting and lowering.
- Whether the cylinder requirement calls for low closed height, high tonnage, long stroke, load holding or even controlled lowering as well as raising there are a wide variety of cylinders to suit most applications.

Equipment Capability

Types of Hydraulic Cylinders

- Typical cylinder construction



Equipment Capability

Types of Hydraulic Cylinders – RLP & RFJ Series

- These cylinders have relatively low collapsed heights in relation to stroke length.
- They are single acting with spring return and are otherwise known as flat jacks or button jacks

Equipment Capability

Types of Hydraulic Cylinders – RG Series

- These cylinders have a long stroke length due to their high collapsed height
- They are single acting with spring return and are otherwise known as general purpose cylinders
- Can be very tall and slender so may require a base for stability

Equipment Capability

Types of Hydraulic Cylinders – RHS & RAP Series

- These cylinders have a hollow core which allows them to be used in conjunction with stressing bar and jacking bridge to form a continuous lift
- They can be single or double acting with spring return
- Push / Pull cylinders are very useful in lengthening / shorting applications

Equipment Capability

Types of Hydraulic Cylinders – RSLC & RPLC Series

- These cylinders are high tonnage lock nut cylinders.
- RSLC have a relatively tall collapsed height and a significant stroke while RPLC has a low collapsed height, tilt saddle and shorter stroke
- They are both load return and both ideal for bridge lifting applications.

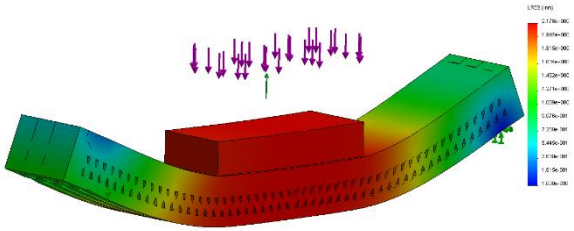
Lift Design

Longitudinal and Lateral Restraint

By jacking a structure in the vertical plane you can avoid unplanned movement in the horizontal plane by providing restraint in the longitudinal and lateral directions. These can include:-

- Existing shear keys but it is important to consider tapered faces
- Temporary works shear keys

Lift Design



Bearing Pressure

It is essential to match the cylinder selection with the support to distribute the bearing pressure over a acceptable surface area.

- Steel packing plates are the only material acceptable to distribute significant forces generated by hydraulic cylinders during a lift.

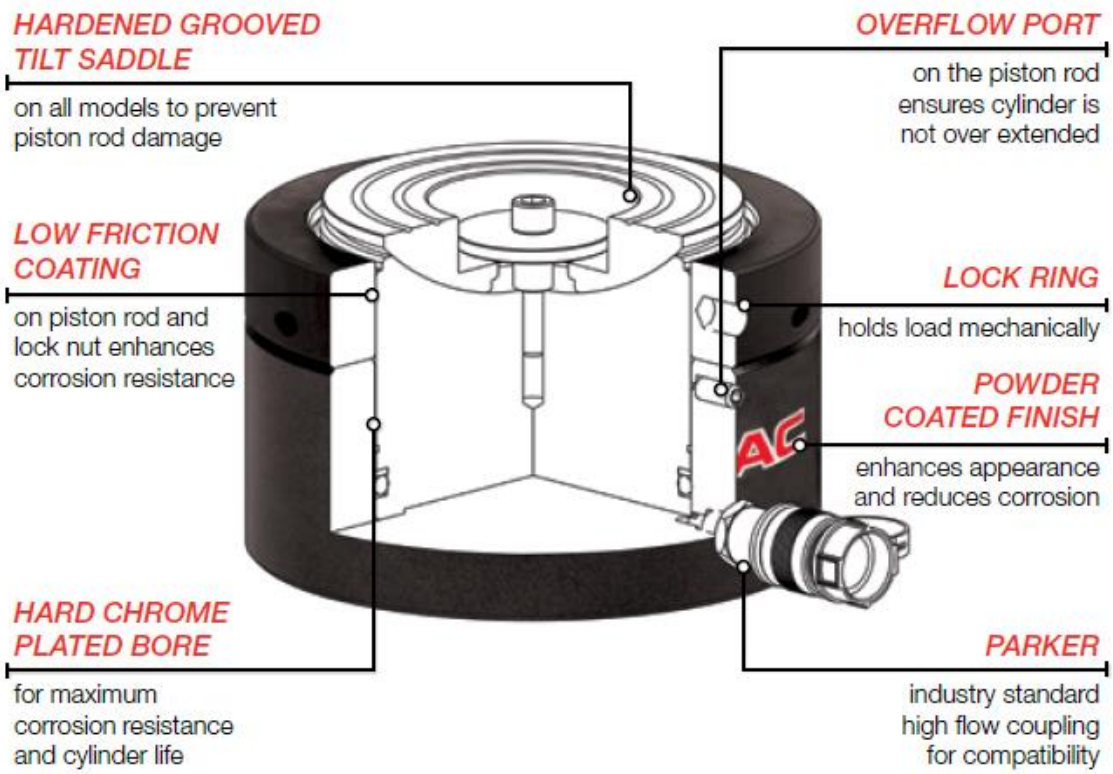
- Cylinders are often mismatched with props or load cells so the load is not evenly distributed across the end section of the supporting component.

Lift Design

Cylinder Selection

Pancake cylinders or RPLC series cylinders are most commonly used for bridge lifting due to their unique characteristics such as :-

- Low collapsed height
- Locking Collar
- Tilt Saddle
- Height Tonnage



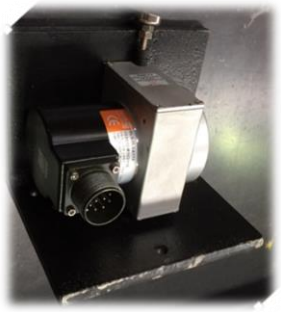
Although they are a load return cylinder which proves difficult at times.

Lift Design

Cylinder Selection

- 80 % rule – cylinder capacity and stroke utilisation
- Ideally utilise 50 – 70% of the cylinders capacity
- Single acting / Double acting / Load return / Lock Nut
- AVOID side loading of cylinders

Stroke Sensor



- Ensure the stroke sensors are connected to the load and/or cylinder and the line is vertical in both planes
- Connect the stroke sensor as close as possible to the jacking location
- Ensure the correct mode / displacement is keyed into the PLC input screen

V66 One Way Valve

- It is good work practice to place a one way valve or hydraulic fuse at each cylinder and have them closed during lifting incase there is an uncontrolled loss of pressure so the load is not dropped

Pressure Transducer

- Relays pressure in each hydraulic line to the computer and then calculates tonnage at each point (pressure x area)

- Can be connected at the Syncmaster or at the cylinder if required

Lift Design

Allowable Differential Between Jacking Points

Often design notes indicate “must be hydraulically linked” but does not specify a tolerance in which each jacking point must be kept relative to the next jacking point or across the whole system between leading and lagging cylinders.

- It is impossible to have uniform displacement and control uniform pressure in a hydraulic system at the same time unless the load is completely symmetrical
- Tolerances of down to 0.5 mm can be achieved depending on the structural characteristics of the structure but if specified a differential of 2 mm is easily acheivable

Lift Design

Input Parameters for a Computer Controlled Synchronous Jacking System

It is ideal to know the following parameters when planning a lift

- Exact theoretical tonnage at each jacking point
- Deviation between jacking points in mm
- Maximum allowable load at the jacking point
- Unknown theoretical point of lift off
- Expected deformation of the jacking point
- Height of lift required
- Head room at each jacking point
- Physical location – grade of jacking surfaces, area to locate cylinder

Conducting the Lift

Stages of a Lift

Set Up

- Connect the furthest hydraulic line then encoder cable to both the machine and at the jacking point then move onto the next location doing one at a time

Check

- Check each stroke sensor is reading movement and each cylinder has been connected to the correct hydraulic port before lifting

Preload

- Used to make contact with the load and settle packers but also to induce some pressure to check for leaks

Check

- Movement at each cylinder, no leaks in the system or hydraulic locks and all cylinders have made uniform contract with the jacking point.

Lift

- Lift in small increments and check pressure and displacement increase relatively uniform

Conducting the Lift

Stages of a Lift

Support

- DO NOT rely on hydraulics to support the load over a long duration. Use a mechanical device like packing or lock nut cylinders

Lower

- ALWAYS restrict the flow using mechanical valves to allow the sync unit time to control the flow of oil returning to the tank. ALWAYS start descending with small increments initially
- The tolerances achieved will be determined by the point where the structure makes contact with its support and load is transferred

Depressurise

- Remove all pressure from the system to ensure there is no energized components before disconnecting the system

Conducting the Lift

Monitoring of a Lift

- It is important to have someone observing the cylinder and jacking location and communicating to the person conducting the lift in conjunction with the information relayed from the control panel of the machine.

- Personnel to monitor:-

  - Even contact of the ram
  - Misalignment of the packing and tilt saddle
  - Deformation of the jacking point
  - Ram overextension
  - Lift off of the structure
  - General contact at the expansion joints
  - Side loading of the cylinder due to lateral movement
  - Wind up the locking collars / mechanical restraint mechanism

Controlled Decent

- The benefits of utilising a synchronous jacking system to automatically lift a load is control in advance but when retracting the valves must be adjusted:

  - Control of the load when raising is relatively easy as you are working against gravity.
  - When lowering it is critical to restrict the return of oil to enable the PLC time to open / close valves and smoothly lower the load
  - This is done by throttling the flow of oil using the V66 one way valve which is connected to each of the advance ports

Analysis of the Process

Recorded Data Files

RAW files cover 3 outputs from the machine:-

Alarm File — 20150316.ALM

Data File — 20150316.CSV

Event File — 20150316.EVT

PRECISION JACKING SERVICES

Project: Engineering - Bearing Realignment Project
Pier: 1
Date: Mon 21st September 2015
Sync System: Durapac Syncmaster Synchronous Jacking System
Cylinders: Durapac RLPC2502 - 250 ton / 2567 kN - 45 mm stroke

SUMMARY

Max Deviation During Lift / Lower across all points	1.2	mm	Pressure - Bar
Max Deviation During Lift across all points	0.4	mm	Extension - mm
Max Deviation During Lower across all points	1.2	mm	Load - Ton
Max Load During Lift on an individual Cylinder	203.4	ton	
Max Total Load During Lift across all Cylinders	356.1	ton	
Total Lift Height - Average	7.7	mm	

21/09/2015	C001Bar	C001Extension	C001Load	C002Bar	C002Extension	C002Load	C003Bar	C003Extension	C003Load	Comments	Average Extension	Max Deviation	Max Load / Cylinder	Max Load Total
16:06:50	387.1	3.7	138.3	91.4	4.7	32.6	425.8	3.7	152.1		4	1	152.1	323
16:06:51	387.1	3.7	138.3	91.4	4.7	32.6	425.8	3.7	152.1		4	1	152.1	323
16:06:52	387.1	3.7	138.3	91.5	4.7	32.7	425.7	3.7	152		4	1	152	323
16:06:53	387.1	3.7	138.3	91.5	4.7	32.7	425.7	3.7	152		4	1	152	323
16:06:54	387.1	3.7	138.3	91.4	4.7	32.6	425.7	3.7	152		4	1	152	322.9
16:06:55	387.1	3.7	138.3	91.5	4.7	32.7	425.7	3.7	152		4	1	152	323
16:06:56	386.2	3.7	137.9	91.5	4.7	32.7	425.4	3.7	151.9		4	1	151.9	322.5
16:06:57	376	3.6	134.3	95.6	4.7	34.1	421	3.7	150.4		4	1.1	150.4	318.8
16:06:58	366.1	3.5	130.8	101	4.7	36.1	417.1	3.7	149		4	1.2	149	315.8
										End of Lift	2.3	1.2	0	0
										MAX	7.7	1.2	203.4	356.1

Benefits of Modern Synchronous Jacking Systems

- Safer - less people around structure and controlled from 1 point
- Quicker - shorter window for down time
- Increased accuracy - approx. +/- 0.5 mm between leading / lagging cylinders
- Data log - insurance that the lift was kept within tolerance
- Weigh / Centre of Gravity
- Added degree of control - Just as easy to lift as to lower the structure
- Lift height from datum
- User friendly program - minimal input screens
- Control unevenly distributed loads - with various cylinder capacities
- Lift parameter alarms – Sync Tolerance / Overload alarms

Conclusion

The remedial works required on bridges and in particular the lifting heavy structures by means of hydraulic cylinders has many factors that need careful consideration during the planning and design phase, equipment selection and correct installation and most importantly the operation to achieve a successful outcome.

The use of a Computer Controlled Synchronous Jacking System is the only viable way to safely lift the structure with full, real time visibility of the loads and displacements with the ability to limit maximum forces and keep adjacent lifting points within prescribed tolerances to minimise applied stresses within the structure.

Additionally having the advantage of full data logging for evidence of displacement and applied load, coupled with the tight control of the lift and the elimination of having people under the structure make synchronous lifting systems a superior choice to manual systems for any bridge lifting appllications.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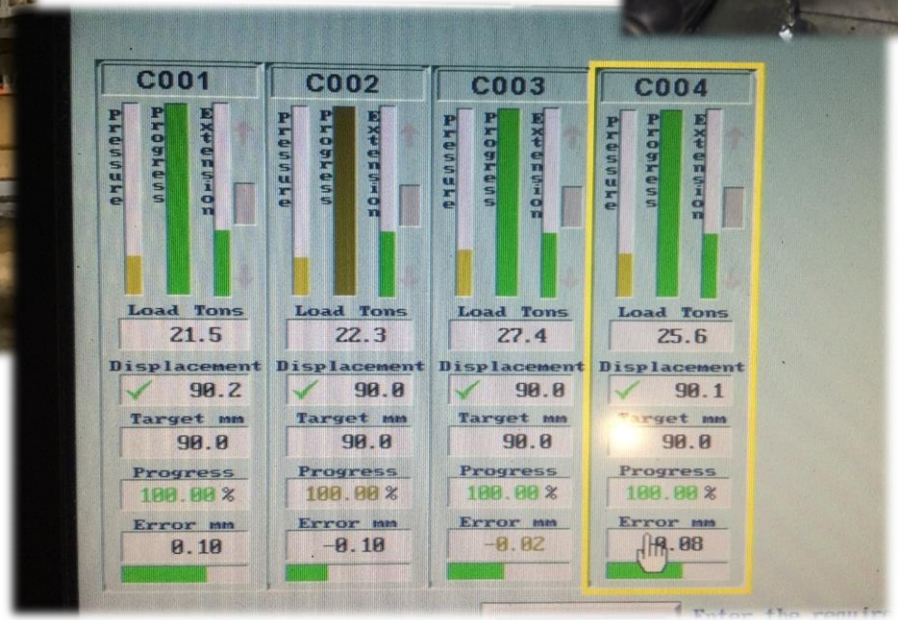
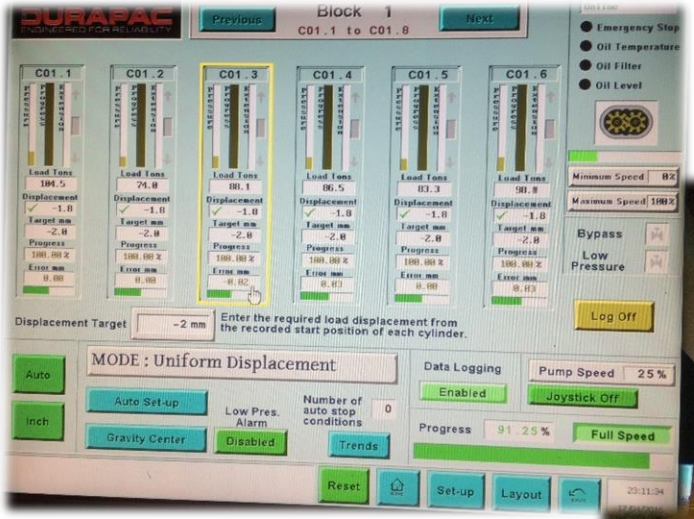
HIRE


C001
Pressure
Progress
Extension
Load Tons
21.5
Displacement
90.2
Target mm
90.0
Progress
100.00 %
Error mm
0.10
C002
Pressure
Progress
Extension
Load Tons
22.3
Displacement
90.0
Target mm
90.0
Progress
100.00 %
Error mm
-0.10
C003
Pressure
Progress
Extension
Load Tons
27.4
Displacement
90.0
Target mm
90.0
Progress
100.00 %
Error mm
-0.02
C004
Pressure
Progress
Extension
Load Tons
25.6
Displacement
90.1
Target mm
90.0
Progress
100.00 %
Error mm
0.08


DURAPAC
ENGINEERED FOR RELIABILITY
Previous
Block 1
C01.1 to C01.8
Next
Emergency Stop
Oil Temperature
Oil Filter
Oil Level
C01.1
C01.2
C01.3
C01.4
C01.5
C01.6
Load Tons
Displacement
Target mm
Progress
Error mm
Minimum Speed 0%
Maximum Speed 100%
Bypass
Low Pressure
Displacement Target -2 mm
Enter the required load displacement from the recorded start position of each cylinder.
Log Off
Auto
Inch
MODE : Uniform Displacement
Data Logging
Enabled
Pump Speed 25%
Joystick Off
Auto Set-up
Low Pres. Alarm
Number of auto stop conditions 0
Gravity Center
Disabled
Trends
Progress 91.25%
Full Speed
Reset
Set-up
Layout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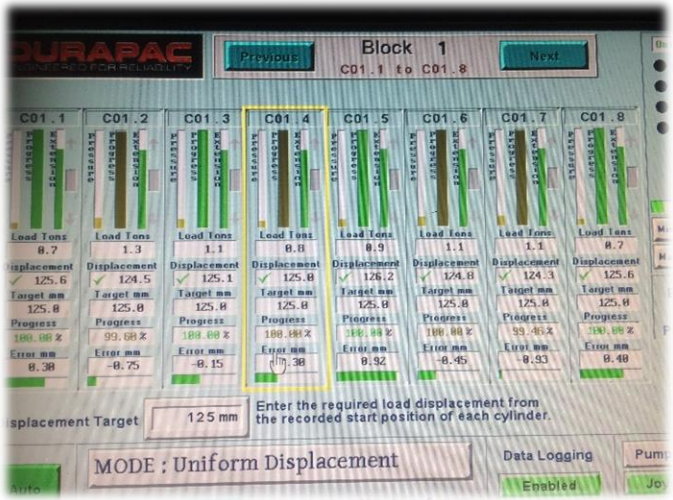
25/11/2014


DURAPAC
Previous
Block 1
C01.1 to C01.8
Next
C01.1
C01.2
C01.3
C01.4
C01.5
C01.6
C01.7
C01.8
Load Tons
Displacement
Target mm
Progress
Error mm
Displacement Target
125 mm
Enter the required load displacement from the recorded start position of each cylinder.
MODE : Uniform Displacement
Data Logging
Enabled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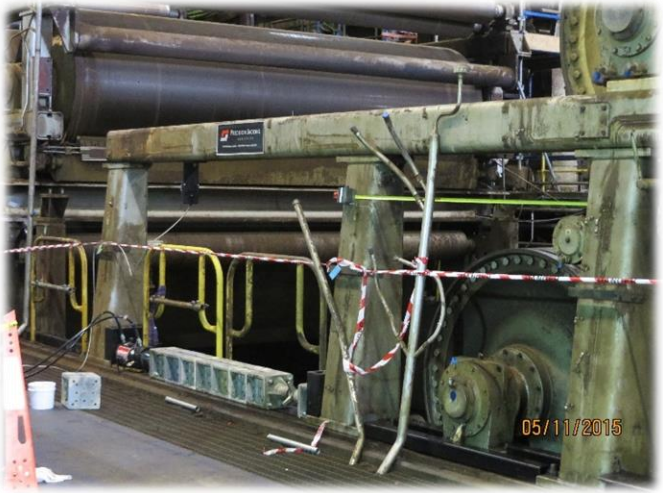
05/11/2015


06/11/2015