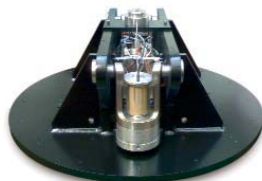




industrial process division



geotechnical centrifuges

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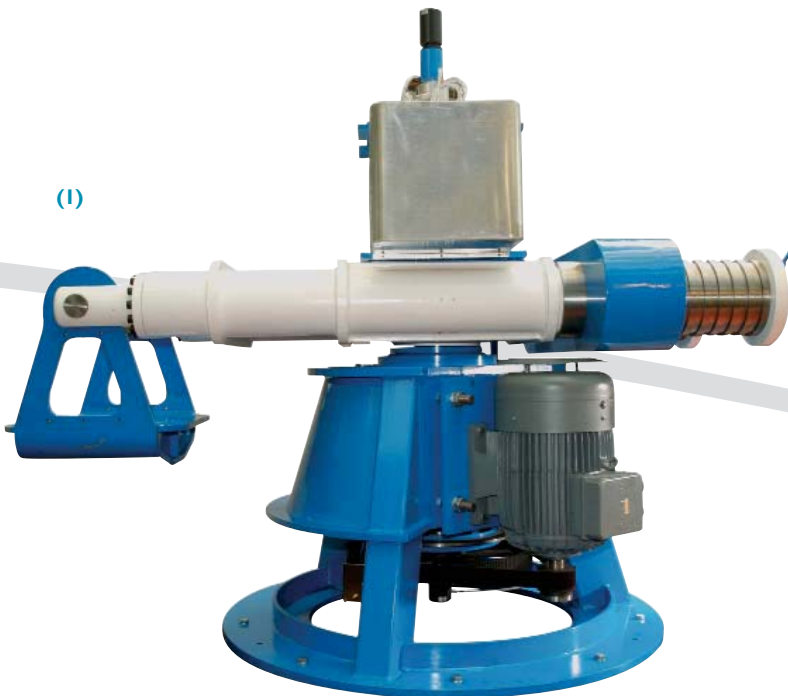
- Key applications of Centrifuge modelling
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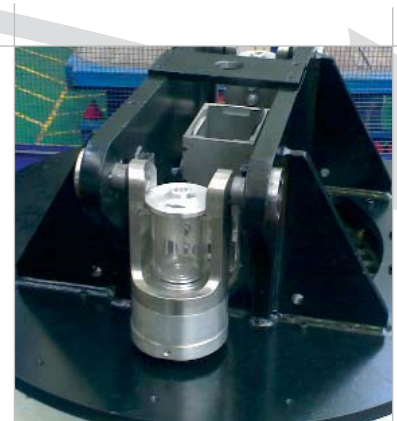
A selection of Broadbent G-Max's Geotechnical client base include :

- | | |
|---|---|
| • UNIVERSITY OF WEST AUSTRALIA, AUSTRALIA | • UNIVERSITY OF RIO DE JANEIRO, BRAZIL |
| • ETH, GEOTECHNICS, ZURICH, SWITZERLAND | • DUNDEE UNIVERSITY, UK |
| • TOKYO INSTITUTE OF TECHNOLOGY, JAPAN | • ETH, MINERALOGY, ZURICH, SWITZERLAND |
| • TOYO CONSTRUCTION, JAPAN | • NOTTINGHAM UNIVERSITY, UK |
| • KISOJIBAN CONSTRUCTION, JAPAN | • UNIVERSITY OF TEXAS AT AUSTIN, USA |
| • CAMBRIDGE UNIVERSITY, UK | • DALIAN UNIVERSITY OF TECHNOLOGY, PR CHINA |

(1)



(2)



(1) - Modular beam centrifuge GMB GT50/1.7
 (2) - Permeameter rotor for hydraulic conductivity testing

KEY APPLICATIONS OF CENTRIFUGE MODELLING

The primary scientific reason for the use of centrifuge modelling to investigate geotechnical systems is due to the dominance of material self-weight. The fundamental mechanical behaviour of soil is highly non-linear and stress-level dependent and to simulate accurately a prototype at small scale, the in situ stresses must be reproduced correctly in the model. In order to replicate these gravity induced stresses of a prototype in a 1/Nth scale model, it is necessary to test the model in a gravitational field N times larger than that of the prototype.

Thus the dimensions and many of the physical processes of the prototype can be scaled correctly if an Nth scale model is accelerated by N times the acceleration due to gravity. Physical modelling plays a vital role in geotechnical engineering in the following areas:

- **PARAMETRIC STUDIES**
- **INVESTIGATION OF NEW PHENOMENA**
- **VERIFICATION OF ANALYTICAL OR NUMERICAL METHODS**

The physical modelling of soil behaviour under load has always played a pivotal role in helping design engineers acquire a better understanding of the actual behaviour under similar stress conditions of real construction projects.

In particular, centrifuge modelling is currently regarded as an invaluable means of soil testing that markedly enhances the understanding of the physical behaviour of soils under complex static or dynamic situations. Examples include:

- **SLOPE STABILITY**
- **RETAINING STRUCTURES**
- **EMBANKMENTS**
- **FOUNDATIONS**
- **PILE – SOIL INTERACTION**
- **TUNNELS**
- **HEAT TRANSFER**
- **DIFFUSION**
- **SEEPAGE**
- **EARTHQUAKES**
- **WAVE LOADING**
- **CONTAMINANT TRANSPORT**
- **FREEZE/THAW**
- **EFFECTS OF DEEP MINING**

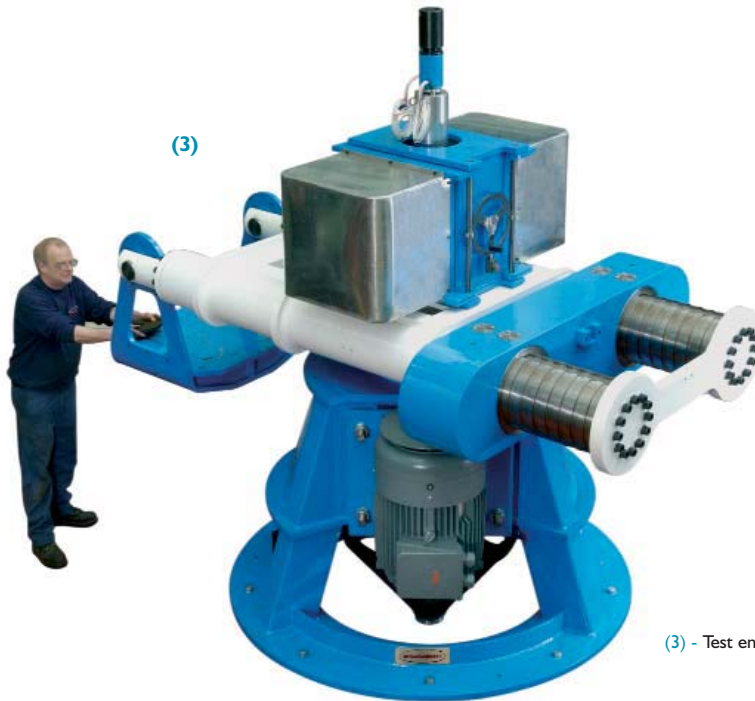
By creating stress conditions in a small soil laboratory model, where the effects of gravity on a real structure on real ground conditions are simulated by generating a centrifugal force field throughout the soil sample, geotechnical research scientists and engineers can obtain insight into the factors affecting geotechnical risk in major and complex construction projects.

Centrifuge testing of soils is a recent development in geotechnical modelling that is growing rapidly worldwide, having had its birth in the UK in the early 1980s. Centrifuge modelling enhances markedly the understanding of the physical behaviour of soils under complex static or dynamic stress fields, and has been successfully applied to classical engineering problems.

Traditional laboratory techniques, such as triaxial, consolidation, shear box and penetrometer testing have been accepted for many years as providing useful support data in adumbration of field site survey information but they are too limited in scope to provide the detailed and incontrovertible scientific evidence required for the newly emerging approach to the geotechnical risk management of major projects.



MODULAR CENTRIFUGE: GMB/D GT50/1.7 GT880/2.2



(3) - Test environment I: 1.7m 50g-Tonne beam

Beam Systems

PLATFORM RADIUS	2.0m
PAYLOAD EFFECTIVE RADIUS	1.7m
MAXIMUM PAYLOAD SIZE	W = 0.6m circumferential, L = 0.8m wide (vertical in flight) H = 0.9m high (radial in flight)
100G PERFORMANCE	500kg at 100g at 1.7m radius (230rpm)
MINIMUM ACCELERATION	500kg at 10g at 1.7m radius (75rpm)
MAXIMUM PERFORMANCE	330kg at 150g at 1.7m radius (280rpm)
IN-FLIGHT BALANCING CAPABILITY	From a maximum +/- 50kg-m (+/- 30 kN at 230rpm, +/- 45kN at 280rpm)
MAXIMUM RESIDUAL OUT OF BALANCE	to a residual value of less than +/- 1.7 kg-m (+/- 1 kN at 230rpm, +/- 1.5kN at 280rpm) +/- 50kN
DRIVE MOTOR	55kW - 4 pole - 415V - 3 phase - 50Hz, D250M frame induction motor
INVERTER	55kW PWM non-regenerative inverter
PLANE STRAIN BOX (INTERNAL)	0.2m circumferential x 0.7m wide x 0.4m high
AXISYMMETRIC TUB (INTERNAL)	0.5m diameter x 0.5m high
USER HYDRAULIC UNIONS	4 ports air/water/oil, 10 bar g, 10 to 50°C

Drum Systems

G-LEVEL AT CHANNEL WALL	Maximum 440g
CHANNEL ASPECT RATIO	L x W x D, 2.2m x 0.80m x 0.30m
MAXIMUM SPEED	600rpm
CHANNEL VOLUME	1.6m ³
SOIL PAYLOAD	2 tonnes at 440g, 880g-tonnes
TOOL TABLE DRIVE	Servo controlled
TOOL TABLE AT REST	Start, stop capability with integrated safety shield
TOOL TABLE PAYLOAD	180kg
OUT OF BALANCE FOR CHANNEL	Maximum 10kgm at 440g, 22.5kg at 200g
OUT OF BALANCE FOR TOOL TABLE	Maximum 1kgm at 440g

MODULAR CENTRIFUGE: GMB/D GT50/1.7 GT880/2.2

Beam and Drum Systems

FABRICATION

MATERIAL

WELDS

PAINT

High strength structural carbon steel

Non destructively tested

To Broadbent standard: optional client specification

INSTALLATION SPECIFICATIONS

FLOOR SPECIFICATION

Concrete foundation and reinforced enclosure required

(Enclosure design details available on request)

VIBRATION ISOLATION

Rigid mount, no vibration isolation available due to low RPM of beam

CONTROL AND INSTRUMENTATION

EMBEDDED LOGIC

PLC controller

INTERLOCKS / GUARDS

Designed and built to BS 5304

VIBRATION MONITORING

Accel / LC monitoring with vibration alarms and drive trip

SPEED SENSORS

Speed measurement by proximity switch and toothed disk

MOTOR PROTECTION

Motor thermistor and over current protection

The aspect ratio of the soil channel is 2.2m diameter x 0.80m wide x 0.30m deep. Smaller test environments are available. The drum centrifuge environment produces high acceleration levels due the aerodynamic efficiency of the ring channel. The 2.2m environment produces a radial acceleration of 440g on a test payload of 2 tonnes.

At 400g the prototype dimension modeled are:

- **SAMPLE LENGTH** **2765M**
- **SAMPLE WIDTH** **320M**
- **SAMPLE DEPTH** **120M**
- **SAMPLE VOLUME** **100M³**

Twin concentric shafts allow separate control of a central tool table and the soil ring channel. Together with multipurpose test specific actuators and robotic servo controllers, which can be fitted to the tool table, radial, circumferential and vertical control of construction processes or test activities may be modelled.

The drum is mounted on the outer of the two shafts, which is rotated by the main centrifuge drive motor, common to both test environments. The inner shaft is connected to a separate tool table on which test specific actuators can be mounted. These shafts can be linked to rotate together, or can be operated independently of each other. In the latter case, a separate closed loop position and velocity servomotor drives the inner shaft.

A safety shield offers complete protection when manual access to the stopped inner table is required. This feature isolates the user from the rotating faces of the drum ring channel when the tool table is stopped.

Safety shield not shown in photographs.

(4)



(4) - Test environment 2: 2.2m diameter, 880g-tonne drum

MODULAR DRUM CENTRIFUGE: 1.4M GMD GT450/1.4

The GMD series of centrifuges are drum centrifuges for civil engineering research and teaching. Drum centrifuges with their high acceleration capability and large model surface area, have enabled modelling of pile-foundation interaction grouting, cold regions, pollution migration and associated remedial measures.

Thomas Broadbent and Sons Ltd., fully support their Geotechnical drum centrifuge range with on site commissioning and maintenance agreements. Coupled with an extensive range of test specific instrumentation and equipment provide a complete turn key service for the civil engineer end user.

The GMD series offers standard laboratory floor installation with anti vibration isolation. Large expensive specialist concrete containment structures are not required with the GMD centrifuge.

(5)



(7)



(6)



(8)



- (5) - GMD GT450/1.4
- (6) - **Drum Siphon Drain** - Model fluid level control over entire speed range of centrifuge. Siphon works on drainage channel plumbed to drum drains. The drainage channel is mounted beneath drum channel.
- (7) - **1.4m Diameter** - 450g-tonne drum channel-complete with multiple drainage points, bottom mounted siphon drainage channel (not shown) and soil partition box quadrature mounting points.
- (8) - **Centrifuge Modularity** - The drum is removed and a permeameter rotor added to create a high g, hydraulic conductivity testing environment, designated GMP GT18/1.5.

TECHNICAL SPECIFICATION OF GMD GT450/I.4

Base Machine

MAXIMUM SPEED	875rpm
MAXIMUM ACCELERATION VERTICAL	600g at 0.7m radius
DRUM CHANNEL ASPECT RATIO	4.4m circumferential, width 0.35m, depth 0.27m
DRUM CHANNEL VOLUME	0.42m ³
SOIL PAYLOAD: MAXIMUM	750kg at 600g, 450 g-tonne
RING CHANNEL SOIL PARTITION BOXES	2 off
TOOL TABLE PAYLOAD	120kg
TOOL TABLE DIAMETER	0.75m
OUT OF BALANCE FOR CHANNEL	2.5kg-m at 600g max
OUT OF BALANCE FOR TOOL TABLE	0.5kg-m at 600g max
TOOL TABLE SYSTEMS	
USER HYDRAULIC UNION	2 ports air/water/oil, 10 bar g, 10 to 50°C
ELECTRICAL SLIP RING STACK: CONTROL	50 rings, 1000V RMS at 7.5A ea
ELECTRICAL SLIP RING STACK: VIDEO	2 x high bandwidth 50 MHz video channels
FIBRE OPTIC ROTARY JOINT	Single mode, rated 1000rpm, 2 x ethernet to fibre media converters
INTEGRATED DAS	32 channel, 200 kHz, 16 bit, on board ethernet based
DRUM SYSTEMS	
FLUID IN	2 x fluid feeds to drum
FLUID OUT	Remote controlled siphon drain
ELECTRICAL SLIP RING STACK: CONTROL	36 rings, 1000V RMS at 7.5A ea
ELECTRICAL SLIP RING STACK: VIDEO	2 x high bandwidth 50 MHz video channels
INTEGRATED DAS	32 channel, 200 kHz, 16 bit, on board ethernet based
FABRICATION	
MATERIAL	High strength structural carbon steel
WELDS	Non destructively tested
PAINT	Broadbent standard - optional Client specification
INSTALLATION SPECIFICATIONS	
FLOOR SPACE	4m x 4m, allowing access for drum channel removal
FLOOR SPECIFICATION	Flexible mount: anti vibration floor isolators to permit laboratory floor location
CONTROL AND INSTRUMENTATION	
EMBEDDED LOGIC	PLC controller
INTERLOCKS / GUARDS	Designed and built to BS 5304
VIBRATION MONITORING	Accelerometer monitoring with vibration alarms and drive trip
SPEED SENSORS	Speed measurement by proximity switch and toothed disk
MOTOR PROTECTION	Motor thermistor and over current protection



HIGH G MINERALOGY TABLE MT GT150/1.6

The High g mineralogy table offers a platform to conduct high gravity, large payload, tests in a safe laboratory environment. Primarily aimed at producing high gravity fields for mineralogy research to model deep earth, sub surface melt processes, the centrifuge equally offers a robust platform to facilitate small scale machine modularity offering a drive platform to accommodate small beam rotors and drum ring channels for lower g geotechnical modelling.

With a view to further extend the scope and flexibility of this product, the 3000g centrifuge can be further upgraded to offer large payload hydraulic conductivity testing by adding a permeameter rotor to the main drive shaft, complete with fluid unions and data acquisition. Hence with one base machine acquisition the following four detachable test environments can be supplied to offer the complete high g earth testing platform:

- **HYDRAULIC CONDUCTIVITY: 45kg to 3000g**
- **GEOTECHNICAL DRUM MODELLING: 1.4m DIAMETER, 400g**
- **GEOTECHNICAL BEAM MODELLING: 0.55m EFFECTIVE RADIUS, 200g**
- **MINERALOGY TESTING: 1.3m TABLE, 3000g**

The centrifuge containment enclosure provides machine integrity and safety at all acceleration levels. The small foot print allows easy, floor mount emplacement. Vibration isolators permit the location of the centrifuge in a standard soils laboratory environment. Though for anticipated continuous high g runs pit mounting offers additional security.

MT GT 150/1.6

- **1.6m DIAMETER TABLE**
- **MAXIMUM SPEED 2850rpm**
- **MAXIMUM ACCELERATION 3000g AT 0.33m RADIUS**
- **TABLE PAYLOAD 45kg AT 2850rpm (BALANCED)**
- **2.1m², SMALL FOOTPRINT**
- **INTEGRAL SAFETY CONTAINMENT ENCLOSURE**
- **300A AC POWER SLIP RINGS**
- **INSTRUMENTATION SLIP RINGS**
- **ON BOARD DAS**
- **2 PORT HYDRAULIC ROTARY UNION**

(9)



(10)



(9) - MT GT150/1.6 - Safety enclosure casing not shown for clarity

(10) - Table apertures with 45kg hydraulic ram test payload and counter weight for testing to 3000g

HIGH G MINERALOGY TABLE MT GT150/1.6

Base Machine

WEIGHT	3900kg
DIAMETER	1.64m
MAX WIDTH WITH VIBRATION ISOLATORS	1.9m
HEIGHT	2.0m
MAXIMUM TABLE SPEED	2850rpm
MINIMUM TABLE SPEED	300rpm
MAXIMUM TABLE ACCELERATION	3000g at 0.33m diameter at 2850rpm
TABLE WEIGHT	860kg
TABLE PAYLOAD	45kg at 2850rpm
TABLE PAYLOAD VOLUME	0.025m ³
TABLE PAYLOAD CENTRE	0.33m radius
CENTRIFUGE DRIVE	55kW AC inverter drive
DRIVE TRANSMISSION	Toothed belt
POWER SLIP RING STACK	30 rings 500 VDC at 20A ea
INSTRUMENTATION SLIP RING STACK	26 rings at 50 VDC at 1A ea
HYDRAULIC ROTARY UNION	2 ports air / water 7 bar-g at 2850rpm

FABRICATION

MATERIAL	High strength structural carbon steel
WELDS	Non destructively tested
PAINT	To Broadbent standard: optional client specification

INSTALLATION SPECIFICATIONS

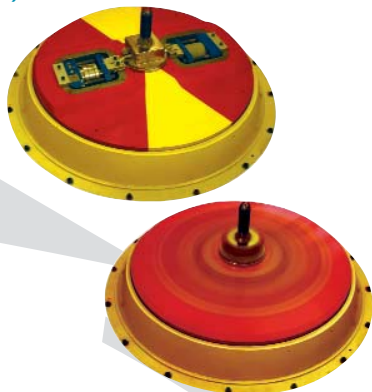
FLOOR SPACE	4m x 4m for easy access
FLOOR SPECIFICATION	Flexible mount: anti vibration floor isolators to permit laboratory floor location

CONTROL AND INSTRUMENTATION

EMBEDDED LOGIC	PLC controller
INTERLOCKS / GUARDS	Designed and built to BS 5304
VIBRATION MONITORING	Accelerometer monitoring with vibration alarms and drive trip
SPEED SENSORS	Speed measurement by proximity switch and toothed disk
MOTOR PROTECTION	Motor thermistor and over current protection



(11)



(11) - 3000g Laboratory test environment

ONBOARD ETHERNET BASED DATA ACQUISITION SYSTEMS

Our geotechnical data acquisition systems are designed for high gravity operation, Windows based; with multi-channel, on-board digitisation, utilising TCP/IP networked communication and control. The LAN based architecture of the data acquisition systems permits a total solid-state hardware implementation that excludes the need for any rotating data storage media such as hard disk drives and any cooling fans.

Typical Data Acquisition System (DAS) Specifications

ADC specification

Type: successive approximation
 Resolution: 16 Bit
 Max sampling: 200 kHz
 Conversion: 5µs
 Linearity: +/- 1 bit

Analogue Input and Output

Input channels: 8 DE, expandable to 256 DE
 Band width: 500KHz
 Ranges: bipolar: +/-10v, +/- 5v, +/- 2.5v, +/- 1.25v, +/- 0.625v, +/- 0.312v, +/- 0.156v
 Output channels: 4 DAC
 DAC resolution: 16 bits
 Update rate: 100kHz
 Output range: +/- 10v

Digital I/O

Input: 24 bits isolated, individually programmable
 Output: 24 bits isolated, individually programmable
 Dig I/O expandable: 272 bits
 Frequency/pulse: 2 x frequency/pulse 16 bit Generator channels
 4 x cascable frequency/pulse 16 bit counter channels

High g Transducer Interfacing

Channel capacity: 16 to 128 channels
 Enclosures: integrated to drum or on beam located centrally and arm end
 High g signal conditioning: multichannel channel decade software PGA and transducer PSU cards
 g-rating: 400g
 PGA Gain: x1, x10, x100, x1000
 Transducer excitation: precision +/-10.000v, +/-5.000v
 Connectors: individual channel connections to Mil C-26482

The DAS interfaces directly to the centrifuge via rotating services. These services include, slip ring stacks for electrical power and Fibre Optic Rotary Joints (FORJs) for ethernet communications and control.

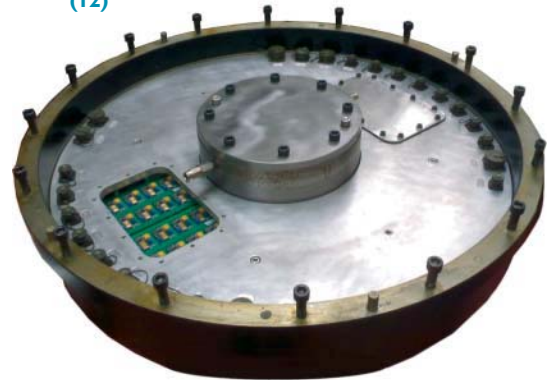
User facilities include:

- **DEDICATED SLIP RINGS FOR TEST AND CONTROL**
- **DEDICATED ANALOGUE VIDEO CHANNELS**
- **HYDRAULIC ROTARY UNIONS**

Information on our range of test specific actuators and instrumentation available on request.

The specification build process will differ greatly between clients. The flexible nature of the system architecture permits customisation of the final DAS delivery to meet the particular requirements of the end user.

(12)



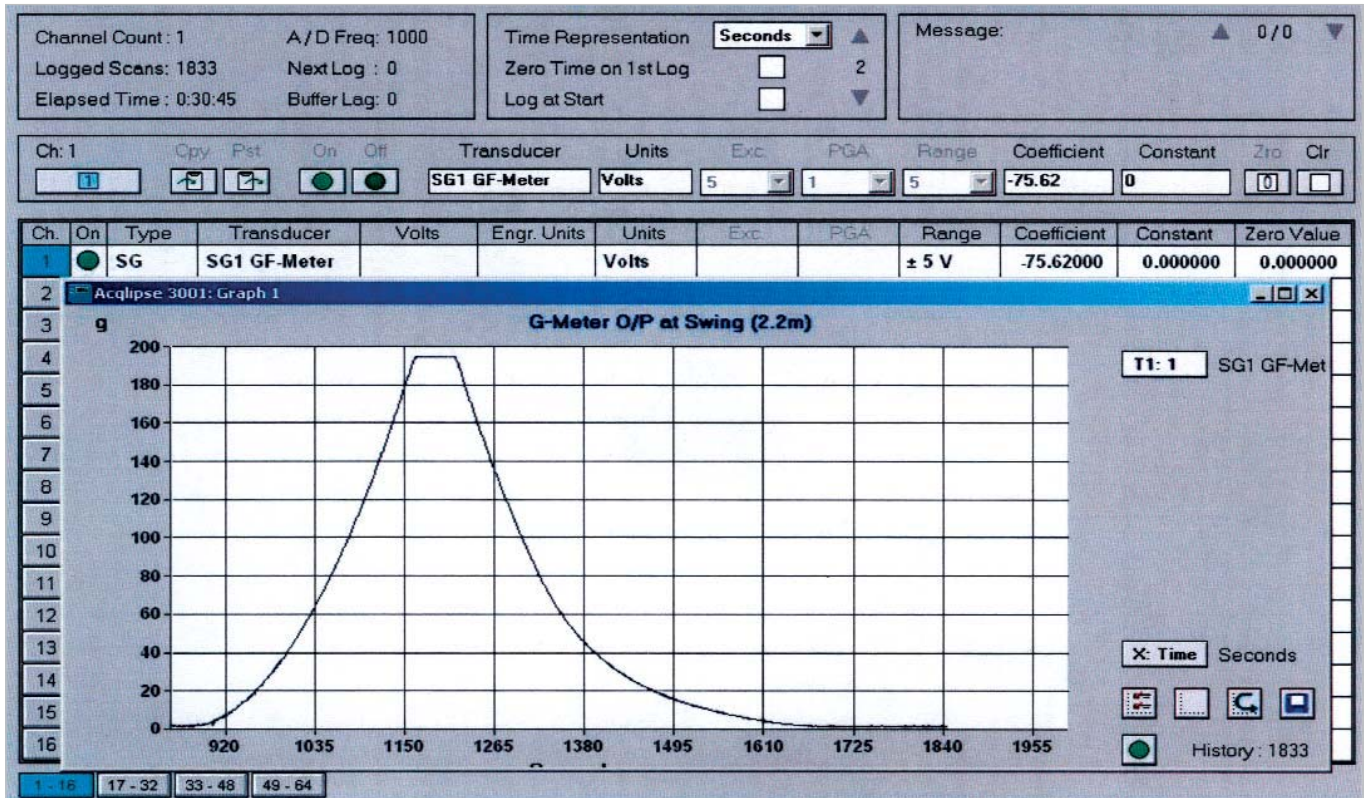
(13)



(12) - Drum - 32 channel 400g drum DAS
 (13) - Beam - 19" swing cabinet frames

ACQLIPSE 3001: ETHERNET BASED DATA ACQUISITION SOFTWARE

(14)



Acqlipse™ interfaces the user to their centrifuge test via a simple, easy to use front end. The standard program environment is designed as a 128 channel, medium speed, data logger interfaced to Ethernet based acquisition hardware mounted on the centrifuge. For drum and tool table applications the user utilises the first 32 channels only. Currently Acqlipse™ 3001 offers the following standard features:

- **128 CHANNELS AT 1000Hz SAMPLING PER CHANNEL TO DISK**
- **FLEXIBLE LOGGING RATE WITH BUILT IN SAMPLING DIAGNOSTICS TO DETERMINE OPTIMAL AND CONFIRM CHOSEN RATES**
- **INDIVIDUALLY CONFIGURABLE CHANNEL SET UP**
- **INDIVIDUAL OR BLOCK CHANNEL ACTIVATION**
- **TRANSDUCER CALIBRATION**
- **ENGINEERING DATA DISPLAY**
- **PER CHANNEL ZEROING, WITH FLAG INDICATORS AND ZERO OFFSET RECORDING**
- **SOFTWARE SELECTABLE INTEGRATION FOR NOISE REJECTION**
- **X Y PLOTS**
- **MULTIPLE GRAPH WINDOWS, 8 TRACES PER GRAPH, WITH GRAPH SAVE AND RECALL FEATURE**
- **GRAPH REDRAW, WITH USER CONTROL OF NUMBER OF DATA POINTS AND PLOT INCREMENT**
- **INDIVIDUAL TRACE FORMATTING IN REAL-TIME**
- **INDIVIDUAL GRAPH FORMATTING IN REAL-TIME**
- **GRAPH ZOOM FACILITIES**
- **DATA FILE SAVE FORMULATED FOR SPREADSHEET AND TEXT OUTPUT**
- **TEST AUDIT INFORMATION AND COMMENTS SAVED TO FILE**

(14) - Acqlipse™ 3001 graphing panel

ONE COMPANY - MANY SKILLS



Industrial Process Division

Tel: +44 1484 477260
Fax: +44 1484 428041
e-mail: ipd@broadbent.co.uk
Web: www.broadbent.co.uk

Laundry Systems Division

Tel: +44 1484 477243
Fax: +44 1484 516142
e-mail: bls@broadbent.co.uk
Web: www.broadbent.co.uk



Sugar & Sweeteners Division

Tel: +44 1484 477230
Fax: +44 1484 423159
e-mail: sugar@broadbent.co.uk
Web: www.broadbent.co.uk

Service & Spares Division

Tel: +44 1484 477200
24hour: +44 1484 477350
Fax: +44 1484 431821
e-mail: bcs1@broadbent.co.uk
Web: www.broadbent.co.uk



Broadbent Incorporated

P.O. Box 185249, 2509 Gravel Drive,
Fort Worth, Texas 76118. USA.
Tel: +1 (817) 595 2411
Fax: +1 (817) 595 0415
e-mail: broadbent.inc@att.net

Industrial Process Division Geotechnical Section

Tel: +44 1484 477260
Fax: +44 1484 428041
e-mail: geo@broadbent.co.uk
Web: www.broadbent.co.uk



Thomas Broadbent & Sons Ltd.

Queen Street South, Huddersfield, HD1 3EA, England

Tel: +44 1484 477200 Fax: +44 1484 516142

e-mail: tbs@broadbent.co.uk www.broadbent.co.uk



over 135 years of separation technology

Conformity Statement

The centrifuge is designed and constructed in accordance with harmonised Type C standard BS EN 12547 'Centrifuges - Common Safety Requirements'. This ensures compliance with all relevant UK Regulations (Supply of Machinery (Safety) Regulations SI 1992/3073, Electrical Equipment (Safety) Regulations SI 1994/3260, EMC Regulations SI 1992/2372) and EU Directives (Machinery, Low Voltage, EMC). The centrifuge will be CE marked and supplied with a Certificate of Conformity to allow the client to comply with the Health and Safety at Work Act 1974 and the Provision and Use of Work Equipment Regulations SI 1992/2932.

We reserve the right to change specification without notice. 07/06