Locally Made
Equipment for Teaching & Research
in Agricultural Engineering

HYDRAULIC CYLINDERS AS FORCE CELLS

Manual No. 1

R.H. MACMILLAN

Senior Fellow
International Development Technologies Centre
University of Melbourne

r.macmillan@devtech.unimelb.edu.au

LOCALLY MADE EQUIPMENT FOR TEACHING AND RESEARCH IN AGRICULTURAL ENGINEERING

LIST OF TITLES IN THE SERIES

SERIES PREFACE

This manual is one of a series written to make available designs of basic equipment intended to be made by institutions for their own use in teaching and research in agricultural engineering and associated technologies. They are directed at the study of the functional performance of various machines and items of equipment and particularly at the important elements which determine that performance.

As well as providing drawings showing the main dimensions of the equipment, the manuals also include basic theory, design considerations, and techniques for their calibration and use. The designs are based, as far as possible, on the use of industrial components. In addition to specifying part numbers and sources of supply for purchased components, the latter have also been specified, where possible, in terms of size / capacity / performance so that suitable alternatives may be used.

A range of types of transducer from simple manually read devices to more complex electronic units may be used with the designs. In this way the latter can serve a range of users and can remain in use as the level of instrumentation grows.

The designs have been provided by individuals who have had experience in their development and use. We would value comment, criticism, and suggestions for improvements.

The assistance of the Australian International Development Assistance Bureau in providing financial support for the original preparation of the material for publication is gratefully acknowledged. They were originally printed and distributed to interested people by the Editor in 1991.

They are but are now being made available to a wider readership by being republished in a slightly amended form on the ePrints Repository of the University of Melbourne and can be down loaded free of charge at: http://eprints.unimelb.edu.au/

R.H. Macmillan
Editor

Senior Fellow
International Development Technologies Centre
Department of Civil and Environmental Engineering
University of Melbourne
Parkville Victoria 3010 Australia

r.macmillan@devtech.unimelb.edu.au

October 2003

CONTENTS

HYDRAULIC CYLINDERS AS FORCE CELLS

SUMMARY

This manual, which is one of a series on locally made equipment for teaching and research in agricultural engineering, describes the selection, calibration & use of hydraulic cylinders as force cells.

Key words: *Equipment, teaching, research, agricultural engineering, hydraulic cylinder, force measurement.*

'We are lifting the burden from mens' backs and putting it on machines. ' Henry Ford (?)

1.0 INTRODUCTION

Devices for measuring force using hydraulic fluid under pressure are termed hydraulic force or load cells, hydraulic dynamometers or hydraulic force meters. The loaded "element" is oil in the cylinder, the pressure in which is transmitted to a read-out device such as a pressure gauge.

A modern hydraulic cylinder is shown in Figure 1 and a sectional sketch in Figure 2.

Hydraulic force cells have the following characteristics:

(i) rugged in construction;
(ii) may be used for loads of different magnitude by the use of different pressure gauges;
(iii) may be assembled from readily available components, hence are cheap;
(iv) are suitable for relatively constant (non-fluctuating) forces;
(v) have some inherent damping which may be varied by the use of a valve to throttle the flow of fluid between the cylinder and pressure gauge;

(vi) are of only moderate accuracy, particularly if used near the lower limit of their range.

2.0 ANALYSIS

2.1 Theory

The hydraulic force cell consists of a hydraulic cylinder and pressure gauge, together with a length of hose and throttle valve; see Figure 2.

To measure a tension force, the pressure gauge is connected to the "rod-end" of the cylinder. The force on the cylinder acting on the net area (piston area - rod area) creates a hydraulic pressure which is read on the gauge. Thus:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

$$\text{Force} = \text{Pressure}\ \frac{\Pi}{4}\left[(\text{Piston diameter})^2 - (\text{Rod diameter})^2\right] \qquad (1)$$

To measure a compression force, the pressure gauge is connected to the cap or head end of the cylinder and the force acts over the full piston area. Thus:

$$\text{Force} = \text{Pressure}\ \frac{\Pi}{4}(\text{Piston diameter})^2 \qquad (2)$$

If the pressure is read on a pressure gauge, the force can be calculated using these equations. Alternatively, the force cell can be calibrated to give a more accurate value (see Section 5.3.2).

Figure 1: A modern hydraulic cylinder

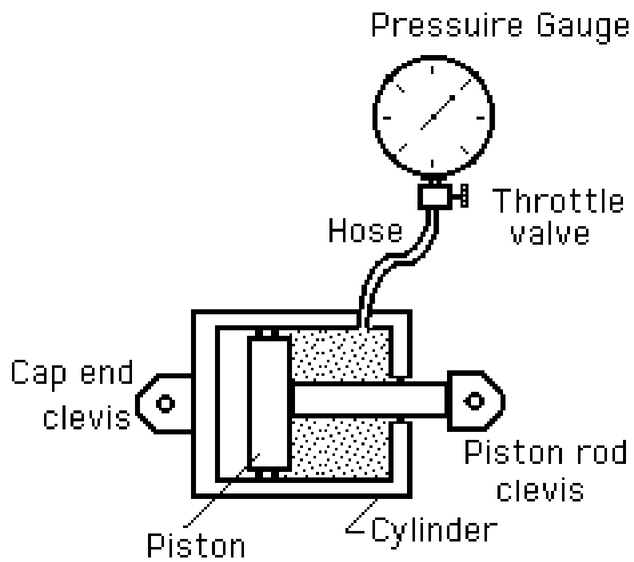

Figure 2: Elements of a force cell

2.2 Design of a Force Cell

In the design of a force cell, there are three variables to be considered:

(i) the magnitude of the force to be measured;

(ii) the cylinder size to be used;

(iii) the range of the pressure gauge(s) to be used.

If the magnitude of the maximum force is known (or estimated) and a cylinder or pressure gauge is already available, then the required size or range of the third variable can be determined directly from the Equation 1 or 2 above.

More frequently, however, the maximum force is known or estimated and it is desired to choose both a suitable cylinder and appropriate pressure gauge to measure loads up to this value. Various combinations of cylinder and pressure gauge may be chosen, but in general smaller diameter cylinders combined with pressure gauges of larger range are likely to offer a cheaper system than vice versa.

The following notes are intended to assist in the selection of components to make hydraulic force cells using standard, commercially available components. Because of their more ready availability, the data has been limited to cylinders with imperial dimensions. If desired, these may be converted to SI equivalent and if a pressure gauge with SI calibration is chosen, the calculated forces will, of course, be in SI units.

3.0 STANDARD COMPONENTS

3.1 Cylinder

It is necessary to choose a cylinder with piston and rod sizes that will generate pressures which are within the safe working range of the cylinder and can be read by commercial pressure gauges.

There is a common range of standard industrial cylinders from 1.5 inch (38.1 mm) to 5 inch (127 mm) diameter. For each piston diameter, there is a range of rod sizes available. These are used at pressures up to 16 MPa (about 2000 lbf /in^2); the maximum pressure depends on their size.

Further details of one series of cylinders (with Imperial dimensions and a medium pressure rating) available from one manufacturer (Parker Hannifin) are given in Table 1.

The stroke of the cylinder is not of importance in actual force generation; it represents a small reservoir of oil that allows for any leakage. Of more importance in a practical sense is the working length of the cylinder, i.e. the length from pin-to-pin.

In specifying the cylinders in this manual, the strokes have been specified so that the pin-to-pin length is constant at 10 inch for the three smaller sizes of cylinder (1.5, 2.0 and 2.5 inch diameter) and 12 inch for the larger (3.25 and 5 inch diameter). If rigs which use these cylinders allow this space, cylinders within the two length ranges will the be able to be moved from rig to rig.

If an 'S' is put in the cylinder specification and a 'special (low friction) seal' will be provided which will reduce the friction in the seal and provide a more accurate measurement. This will reduce the difference between the increasing and decreasing load calibration lines in Figure 3.

Example for specifying a cylinder: A 1.5 inch diameter cylinder (1.5') with a cap end detachable clevis (BC), medium duty (-3L), with BSP parallel ports (R), special seals (S but specify low friction option), with single rod (1) and small male end (4) with UNF threads (A) and 2.62 inch stroke would be specified as:**1.5"BC-3LRS14A2.62.**

3.2 Throttle Valve

Many agricultural operations involve fluctuating forces. It is therefore necessary that the resulting pressure fluctuations be "damped" or "throttled", i.e. reduced in magnitude, if the pressure is to be measured visually. This can be achieved by the inclusion of an adjustable throttle valve in the hydraulic line between the cylinder and the pressure gauge. The valve can be adjusted during the experiment to limit the magnitude of the fluctuations.

It should be noted that the damping of the pressure fluctuations as described above assumes that the fluctuations are not significant to an understanding of the operation being studied. The damping process masks information about the cause of the fluctuations and represents an approximation to the actual loading process. The hydraulic force cells as described in this manual are therefore not suitable for measuring loads with a large dynamic component, or where it is desired to study what is taking place within the time scale represented by one pressure pulse. An electronic measurement should be used in such circumstances.

It is also possible to provide some damping within the body of the pressure gauge by using a gauge filled with a viscous fluid such as glycerine. This can be ordered as "liquid filled".

The throttle valve also allows the pressure gauge to be isolated from the cylinder when readings are not being taken.

The part number for a suitable throttle valve is shown in Table 2, Appendix 1.

3.3 Other Items

(i) *Hose and fittings*
A steel braided hose and associated fittings with a pressure rating in excess of the pressure rating of the cylinder should be used to connect the pressure gauge to the other components. Care should be taken to avoid damage to it; see the warning in Section 5.6. If engine oil is used, the hose must be suitable for use with mineral oil.

In some circumstances, it may be possible to connect the pressure gauge and its associated throttle valve directly to the cylinder.

The part numbers for suitable hose and fittings are shown in Table 2, Appendix 1.

(ii) *Oil*
Any clean engine oil or hydraulic fluid (such as automotive brake fluid) would be suitable for use in the cylinder, provided the hose material is compatible.

(iii) *Manifold*
If it is required to measure a range of loads, it is desirable to have two or more gauges able to be connected to the cylinder as the test progresses. The most convenient way is to mount them together with their throttle valve on a manifold, which itself is permanently connected to the cylinder via the hose. The gauge appropriate to the force being measured is then connected to the cylinder by opening the appropriate throttle valve: all other valves are kept closed.

(iv) *Teflon tape or thread paste*
In order to seal any screwed joints, it is desirable to assemble them with 'teflon tape' or thread paste. Before assembly, the tape is wound onto the thread of the male part in a direction opposite to that used in assembly. Correctly connected joints will not leak. If they do, the cylinder will gradually extend and eventually cease to function. If this occurs, it is necessary to cure the leak and refill the cylinder as described in Section 5.1 or 5.2.

Table 1: Force capacity of cylinders
Imperial units, upper table; SI units, lower table

FORCES THAT CAN BE MEASURED WITH VARIOUS CYLINDERS & PRESSURE GAUGES

IMPERIAL UNITS		TENSION					COMPRESSION				
Piston dia.	inch	1.50	2.00	2.50	3.25	5.00	1.50	2.00	2.50	3.25	5.00
Rod dia.	inch	0.625	0.625	0.625	1.00	1.00					
Nett area	sq inch	1.46	2.83	4.60	7.51	18.85	1.77	3.14	4.91	8.30	19.64
Pressure gauge range lbf/sq in	Max design pressure lbf/sq in										
0-100	75	110	210	350	560	1410	130	240	370	620	1470
0-160	120	180	340	550	900	2300	210	380	590	1000	2400
0-200	150	220	430	690	1100	2800	270	470	740	1200	2900
0-300	225	330	640	1040	1700	4200	400	710	1100	1900	4400
0-400	300	440	850	1400	2300	5700	530	940	1500	2500	5900
0-600	450	660	1300	2100	3400	8500	800	1400	2200	3700	8800
0-800	600	880	1700	2800	4500	11300	1100	1900	2900	5000	11800
0-1000	750	1100	2100	3500	5600	14000	1300	2400	3700	6200	14000
0-1600	1200	1800	3400	5500	9000	23000	2100	3800	5900	10000	24000
0-2000	1500	2200	4300	6900	11000	28000	2700	4700	7400	12000	29000

S.I. UNITS		TENSION					COMPRESSION				
Piston dia.	mm	38.1	50.8	63.5	82.6	127.0	38.1	50.8	63.5	82.6	127.0
Rod dia.	mm	15.87	15.87	15.87	25.40	25.40	-	-	-	-	-
Nett area	sq mm	942	1829	2969	4845	12161	1140	2027	3167	5352	12668
Pressure gauge range MPa	Max design pressure MPa										
0-0.6	0.45	0.4	0.8	1.3	2.2	5.5	0.5	0.9	1.4	2.4	5.7
0-1.0	0.75	0.7	1.4	2.2	3.6	9.1	0.9	1.5	2.4	4.0	9.5
0-1.6	1.2	1.1	2.2	3.6	5.8	15	1.4	2.4	3.8	6.4	15
0-2.5	1.9	1.8	3.4	5.6	9.1	23	2.1	3.8	6.0	10	24
0-4.0	3.0	2.8	5.5	8.9	15	36	3.4	6.1	9.5	16	38
0-6.0	4.5	4.2	8.2	13	22	55	5.1	9.1	14	24	57
0-10.0	7.5	7.1	14	22	36	91	8.6	15	24	40	95
0-16.0	12.0	11	22	36	58	146	14	24	38	64	152

NOTES:

1. The numbers in the body of the table above show the forces that can be measured using cylinders with the piston / rod areas shown in the top rows and with pressure gauges having pressure ranges shown in the L.H. Column; lbf, uper table; kN lower table
2. The minimum force that can be measured is approximately 10% of the max.
3. The forces shown below the line are not recommended for Parker medium duty cylinders (type 3L) because they exceed the maximum recommended values for the fittings, or the corresponding pressures exceed the maximum recommended values for the cylinder, or both.
4. For selection purposes only, most numbers have been rounded to 2 significant figures.

3.4 Pressure Gauge

A number of standard pressure gauges is also available with ranges (relevant to this work) varying from 0 - 100 lbf/in^2 to 0 - 2000 lbf/in^2; corresponding gauges with SI calibration are from 0 - 0.6 MPa to 0 - 16 MPa. Values chosen from the current Australian Standard 1349 -1986 are shown down the LH side of Table 1 under the heading 'pressure gauge range'.

The selection of a pressure gauge is dependent on a number of factors:

(i) The nominal (i.e. approximate) maximum force to be measured.
This must be estimated from experience, handbook data or results published by other workers. Because the actual maximum force is on occasion likely to exceed the nominal value, it is usual to make some allowance for this by selecting a gauge, so that the 'working pressure' (calculated using the nominal maximum force to be measured) is equal to 75% of the pressure range for the gauge. These values for the standard gauges have been indicated under the column headed 'maximum design pressure' in Table 1.

(ii) Fluctuations in the force.
As noted above, there are frequently pressure fluctuations in load cells used for measuring forces. The 25% excess range provided above (and a further 25% overload in the gauge mechanism) will allow these fluctuations to occur without damaging the gauge. Also, as noted above, they can be dampened out by the use of the throttle valve (see Section 3.2 above).

(iii) The minimum force to be measured.
It is recommended that because of friction in the hydraulic cylinder, the lowest 10% of the range of the pressure gauge should not be used for measurement of force. The minimum force will be the force corresponding to about 10% of the maximum pressure and will thus be 10% / 75%, or about 1/8 of the maximum design force.

If it is desired to measure smaller forces than this, it is preferable to use a pressure gauge with a lower range. Two or more gauges can be mounted on a manifold (as described in Section 3.3 (iii)); the throttle valve for the gauge appropriate to the force being measured is then opened.

4.0 SELECTION OF COMPONENTS

Tables 1 and 2 also shows (in Imperial and SI units respectively) the tension and compression forces that can be measured with various sizes of hydraulic cylinder (shown across the top) using various pressure gauges (shown down the LH side).

As noted above, the maximum force to be measured is frequently only known approximately. Hence in preparing these Tables allowance for this uncertainty has been made by making the maximum design pressure only 75% of the maximum pressure for each gauge. If the maximum force is known accurately, then the selection can be based on the maximum pressure. If the maximum force is quite uncertain, then a design pressure less than 75% of maximum may be warranted.

In any event, there is a further safety factor in that pressure gauges will usually withstand some over-pressure (25%) without failure. However, it is best not to rely on this because it is intended to allow for extreme situations.

Hence if the nominal maximum force is known, inspection within the body of the table will reveal combinations of cylinder sizes and pressure gauges which will measure that force.

Examples (some values have been rounded):

(i) If it is desired to measure tension forces of up to about 2000 lbf, inspection of Table 1 will show the combinations of cylinders and pressure gauges that will be satisfactory. Some of these are shown below.

Range of Pressure Gauge, lb/in2	Hydraulic Cylinder Dia, inch		Force measured lbf (approx)	
	Piston	Rod	Max.	Min.
0 - 2000	1.5	0.625	2200	300
0 - 1000	2	0.625	2100	250
0 - 600	2.5	0.625	2100	250

Table 2: Examples of cylinders suitable for measuring forces up to 2000 lbf

The choice between the above, which will all be satisfactory in principle, can be made on the basis of cost. In general, the smaller cylinder with the pressure gauge of higher range will be cheaper than the larger cylinder and pressure gauge of lower range.

(ii) If it is desired to measure compressive forces between 1kN and 20kN, inspection of Table 2 shows that a cylinder with a 63.5 mm (2.5 inch) dia. piston and a pressure gauge with a range of 0 - 10 MPa in will read the maximum force at a pressure slightly greater than the 75%; it will have a minimum reading of 22/8 ≈ 3kN.

A second gauge with a range of 0 - 1.6 MPa will read up to 3.6 MPa and hence will cover the minimum of the larger gauge. The minimum of this gauge will be 3.6/8 ≈ 0.5 kN, which is less than the minimum of 1 kN required. The gauges can be mounted on a manifold and connected to the cylinder by opening the appropriate throttle valve as required by the force being measured.

5.0 USE OF THE CELL

5.1 Preparing the Cell for Use in Tension

The objective is to assemble the components and to fill the cylinder and hose with oil.

(i) Ensure that the port in the head end of the cylinder is fitted with a plug and that this has a small hole in it to allow the passage of air.

(ii) Push the piston fully into the cylinder. With the rod end of the cylinder slightly higher than the cap end, fill the cylinder with oil. Shake the cylinder to remove any trapped air; refill if necessary.

(iii) Connect the throttle valve to one end of the hose. With the valve at the bottom (closed) and the hoze held vertically, fill the hose by pouring oil very slowly into the hose, so that it runs down the inner surface of the hose and does not cover its cross section. Shake the hose to remove any trapped air; refill if necessary.

(iv) Connect the free end of the hose tightly to the port in the rod end of the cylinder using teflon thread tape or paste.

(v) Connect the pressure gauge to the valve with teflon thread tape or paste.

The small amount of air (if any) which remains in the tube of the pressure gauge will cause some compressibility in the cylinder, but this will not affect the pressure readings. If there is excessive compressibility (say greater than about 5% of the stroke), it is probable that the cylinder or hose is not completely full of oil. Steps (ii) to (v) should be repeated. Warming the oil slightly will reduce its viscosity and will allow bubbles to escape more easily.

5.2 Preparing the Cell for Use in Compression

The above procedure is followed, except that the oil is placed in the cap end of the cylinder and the pressure gauge is connected to the port in that end.

5.3 Calibrating the Cell

The objective is to determine the relationship between the pressure which is read on the gauge and the force which it is desired to measure. There are two alternative approaches.

5.3.1 Theoretical

Consider a hydraulic cell as shown in Figure 2. In use, the cell is subjected to a working force which it is desired to measure. The pressure can be read from the gauge and the force calculated using the Equations 1(a) or (b).

For any given cylinder, the net area need only be calculated once because it is a constant.
Hence

$$\text{Force} = \text{constant} \times \text{pressure}$$

This is the 'theoretical' calibration and it is reliable because it is based on the basic theory of the cell. However, it makes no allowance for friction in the piston and rod seals.

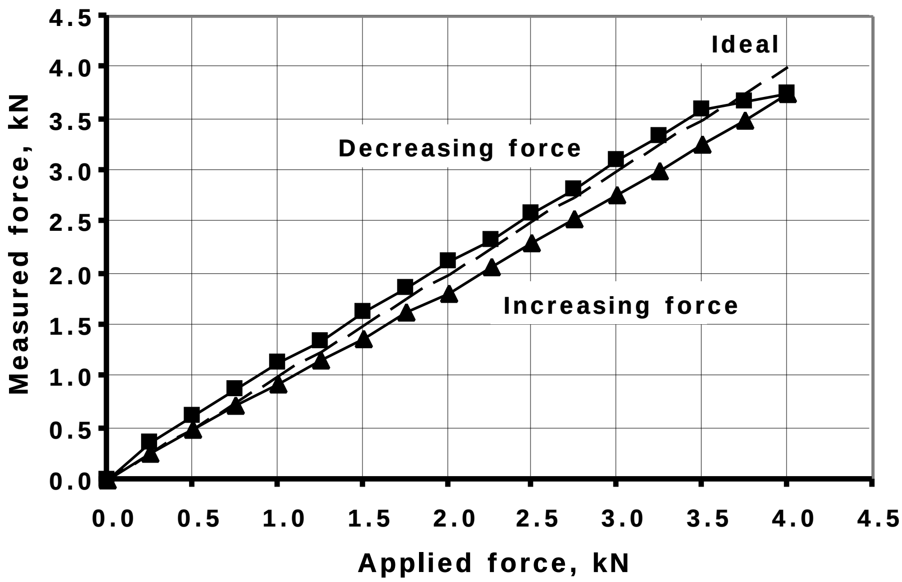

Figure 3 Calibration of a force cell

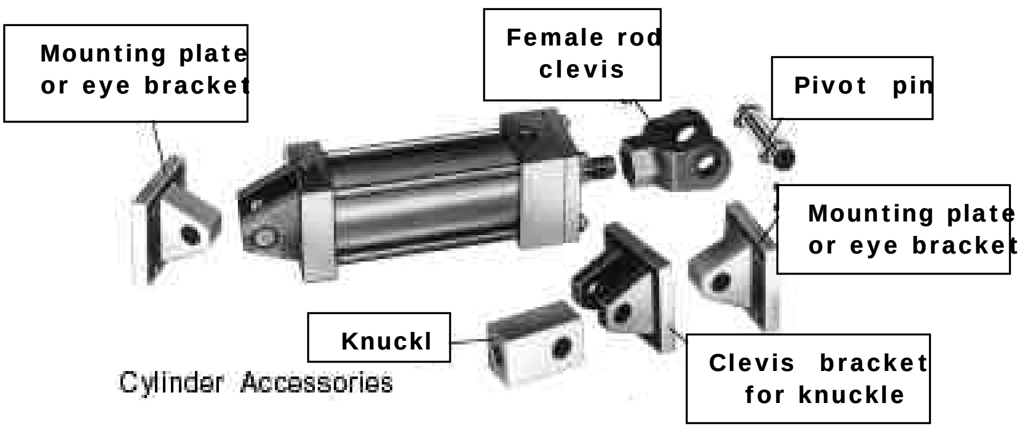

Figure 4: Hydraulic cylinder and accessories

5.3.2 Experimental

To allow for the effect of friction forces on the piston and rod due to the seals (which oppose the applied force, but do not generate pressure) and also any inaccuracies in the pressure gauge, it is desirable to calibrate the force cell and the pressure gauge together, i.e. to determine experimentally the true relationship between the applied force and the reading on the pressure gauge.

In order to do this, it is necessary to apply loads to the cell which are accurately known. These may be obtained from the following:

(i) weights of known magnitude;

(ii) weights of any appropriate magnitude together with a reference force cell which itself has been accurately calibrated;

(iii) a good quality testing machine.

The calibration technique involves:
- applying the known forces to the cell in steps up to a maximum pressure;
- recording the pressure gauge reading and the applied force at each step;
- decreasing the applied force to zero in steps;
- recording the pressure gauge reading and the applied force at each step.

When the results are plotted, it is likely that the calibration graph will be as shown in Fig. 3, which is the calibration of an actual cell.

The question arises as to the significance of the two lines obtained, the lower one for increasing force and the upper one for decreasing force. The difference between two graphs arises from friction forces on the piston and rod due to the seals which oppose the applied force, but do not generate pressure. When the cell is used to measure a fluctuating force, it represents the range of uncertainty within which we cannot determine the exact magnitude of the force.

However, we can draw a line through the points calculated from the mean pressures at each force in the increasing and decreasing direction. This single line represents the calibration and it can be used as described in Section 5.5 below to determine unknown forces.

5.4 Mounting the Cell

In mounting a cell, it is necessary to have an attachment point on the body of the cylinder and on the cylinder rod. These usually take the form of a clevis with associated pin.

- The clevis and associated pin on the cap end of the cylinder are provided as standard.
- The clevis (and associated pin) that screws onto the piston rod can be ordered as required.
- Eye brackets that will match both clevises and can be fitted to the machine to be monitored are also available.

Details of these fittings are shown in Figure 4 and in Table 1, Appendix 1.

Care should be taken in mounting the cell that it is not put under any significant bending force. This can be achieved by ensuring that the mounting pins are arranged at right angles to each other and that the cell has sufficient freedom to rotate on the pins to align itself with the direction in which the force is applied.

5.5 Measuring with the Cell

Before fitting the cell to any machine or measuring with it, it is desirable to make a 'blank' piece of the same length and with the same mounting holes as the cell. This is used when the machine is being transported or when preliminary runs are being made. When everything else is performing satisfactorily, then the cell 'blank' may be replaced by the cell and actual readings taken.

Having plotted the calibration graph, it is used for experimental work by noting down a mean reading of the pressure gauge, for example Q, during an experimental run. Later, the graph is entered at Q and the applied force is read at R.

5.6 Warning

The hydraulic oil in the cylinder may be under high pressure when measurements are being taken. If a hydraulic hose should burst or leak when under such pressure, serious injury may occur due to the fluid penetrating the skin, eyes, etc. It is therefore important to use a steel braided hose and the correct fittings to connect the throttle valve, cylinder and pressure gauge. Those involved in using this type of measuring equipment should keep their face and hands clear and warn others nearby of the danger.

6.0 BIBLIOGRAPHY

Standards Association of Australia (1986):
Australian Standard - Bourdon Tube Pressure and Vacuum Gauges -
AS 1349; 1986 (Second Edition).

British Standard Institution (1985):
British Standard Specification for Bourdon Tube Pressure and Vacuum Gauges
- BS 1780; 1985 (as amended).

British Standard Institution (1986):
British Standard Specification for Dimensions of Basic Features of Fluid Power Cylinders - BS 5755; 1986.

7.0 ACKNOWLEDGEMENT

The assistance of Mr. F. Gerrand, of Mr. B. Lister and Mr. D. Sinclair of Parker Hanifin (Australia) Pty. Ltd. in the preparation, and of Ms. J. Wise in the original typing, of this manual is acknowledged.

APPENDIX 1

Table 1: Details of cylinder and accessories for force cell

DETAILS OF CYLINDER AND PARTS OF FORCE CELL						
Cylinder piston	Diameter, inch	1.50	2.00	2.50	3.25	5.00
	mm	38.10	50.80	63.50	82.55	127.00
Cylinder rod	Diameter, inch	0.625			1.00	
	mm	15.87			25.4	
Cylinder stroke	inch	2.62			2.12	
Length, pin to pin	inch	10			12	
Cap end mounting Clevis (Note 1)	Size, inch	2.0x2.0	2.5x2.5	3.0x3.0	3.75x3.75	5.5x5.5
	Length, inch	1.125			1.875	
	Slot width, inch	0.75			1.25	
	Pin/hole dia., inch	0.5			0.75	
Cylinder model	Parker Part No	1.5BC-3LR14A2.62	2"BC-3LR14A2.62	2.5"BC-3LR74A2.62	3.25"BC-3LR14A2.12	5"BC-3LR74A2.12

titles

Female rod clevis	Pin dia. inch	0.500	0.750
	Width, inch	0.750	1.250
	Length, inch	1.5	2.125
	Thread UNF	7/16-20	3/4-16
	Parker part No	50940	50942

Eye bracket (See note 2)	Size, inch	2.5 x 2.5	3.5 x 3.5
	Hole spacing, inch	1.63 x 1.63	2.55 x 2.55
	Thickness, inch	0.75	1.25
	Length, inch	1.125	1.875
	Hole Dia., inch	0.41	0.53
	Parker part No	69195	69196

Pin (See note 2)	Diameter, inch	0.5	0.75
	Length, inch	1.875	2.625
	Parker part No	68368	68369

NOTES: 1. Cap end mounting clevis and pin supplied as part of cylinder.
2. Eye brackets bolt to attachments. Order 2 brackets & 1 pin if required.

Table 2: Part numbers of accessories for force cell

Part numbers and description of accessories					
Name	Application	Part number	Description	Reqd	Comment
Nipple, cylinder to hoze	1.5",2"&2.5" 3.25" & 5"	4-6-F40X-S 4-8-F40X-S	3/8" BSPP x 7/16"JIC 1/2" BSPP x 7/16" JIC	1 1	S=steel
Hose end assy	All force cells	20642-4-4	7/16" JIC(F) x1/4"hose	2	F=female
Hose	All force cells	421-4	1/4" SAE 100R1AT	2m	Reuseable
Nipple, hose to throttle valve	All force cells	4-4-FTX-S	1/4"NPT x 7/16" JIC	1	
Throttle valve	All force cells	N400S	1/4" NPT (F)	1	
Adaptor,valve to pressure gauge	All force cells	3/8"x1/4"--FG-S	3/8" NPT(F) x 1/4" NPT (M)	1	M=male

APPENDIX 2

Sources of supply of components

HYDRAULIC CYLINDERS, HOSE, FITTINGS AND PRESSURE GAUGES

United Kingdom:
Parker Hannifin (U.K.) Ltd.
P.O. Box 170 Parker House
6 Greycaine Road
Watford WD2 4 QA England
www.parker.com

Australia:
Parker Hannifin (Australia) Pty. Ltd.
9 Carrington Road
Castle Hill NSW 2154 Australia
www.parker.com