

Goodman Jack

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Contents

Introduction & Specifications	1
Setting Up	4
Measurements in Hard Rock	8
Measurements in Soft Rock.....	10
Data Reduction	13
Maintenance	14
Calibrating the Jack	19
References	22
Appendix A	23

Introduction & Specifications

Introduction The Goodman Jack is a borehole probe used for the measurement of wall deformation as a function of applied load. Data obtained from the load-deformation measurements gives the elastic modulus of rock directly. The probe is designed to be used in a NX (3 inch) borehole.

Hydraulic pressure is transmitted to the rock through the movable plates. Two LVDT displacement transducers are mounted within the jack at each end of the movable plates. The system also includes a portable solid-state indicator for measuring displacement, hydraulic pump, pressure gauge, hydraulic hose, and electric cable.

Required Borehole Size The jack is designed for NX boreholes, which have a nominal diameter of 3 inches (76.2 mm).

Effective Jack Force The area of the operating pistons in the jack is such that the maximum hydraulic pressure, 10,000 psi (68.95 MPa), produces the following forces unidirectionally against the rock:

	Bearing Plate Pressure	Total Force against Rock
Hard Rock Jack	9,300 psi (64.12 MPa)	158,000 lb (702.8 kN)
Soft Rock Jack	5,544 psi (38.22 MPa)	94,248 lb (419.2 kN)

LVDTs The two linear variable differential transformer (LVDT) displacement transducers are mounted within the jack. These are Trans-Tek, Model 241-000, which have a linear range of ± 0.1 inch (2.54 mm). The linearity over this range is within $\pm 0.5\%$ of the full scale linear range. The maximum usable displacement range of this LVDT is ± 0.15 inch (3.81 mm). Linearity over the maximum usable range is $\pm 1.0\%$.

Displacement Indicator The portable instrument, Model 52127, operates on internal, rechargeable battery or on 110 volt AC. The displacement of the pressure plate is indicated by two illuminated digital displays, one for each LVDT. These displays give the deviation of the plate from the nominal borehole diameter of 3 inches (76.2 mm) with a sensitivity of 0.001 inches (0.01 mm). A polarity sign indicates whether the deviation is greater than or less than 3.000 inches (76.20 mm). The two voltmeters on the instrument panel give simultaneous readings from each LVDT. These are designated

“near” and “far”, which refers to the proximity of the LVDT to the hose and cable connections on the jack.

As can be seen on the calibration curve, the displacement of the jack is indicated from the fully closed position to the fully open position.

Jack Extension Range	<p>The total displacement or extension of the jack is 0.45 inches (11.4 mm). When the jack is fully closed, the diametrical distance between the outside surfaces of the two pressure plates is 2.75 inches (69.9 mm). When the jack is fully open, the diametrical distance is 3.20 inches (81.2 mm).</p> <p>Note: The jack can be seriously damaged if opened beyond 3.20 inches, so consider this point the practical, safe limit.</p>
Pressure Range	<p>The jack and the hydraulic components are designed for a 10,000 psi (68.95 Mpa) maximum working pressure. The hydraulic pump (Enerpac P-84) produces a maximum output pressure of 10,000 psi (68.95 Mpa).</p>
Pressure Gauge	<p>The pressure gauge (Marsh Type 200) has a bourdon tube sensing element. The accuracy of this gauge is $\pm 0.25\%$ of full scale. The full scale pressure is 10,000 psi (70 Mpa). The smallest division of the scale is equal to 50 psi (0.5 Mpa). Other gauges with different ranges can easily be adapted when necessary.</p>
Power Source	<p>The model 52127 Indicator may be operated: (1) From any standard 60 Hz power source, 105 to 130 volts, single phase, at 8 watts, (2) Internal batteries which are Globe rechargeable gel cell, GC680, or (3) External 12-volt battery which is usually available in a truck, car or drill rig.</p>
Operating Temperature	<p>LVDT: -65°F to 250°F (-54°C to 121°C).</p> <p>Indicator: +10°F to +110°F (-8°C to 43°C).</p> <p>Hydraulic Oil Pour Point: -25°F (-32°C).</p>
Dimensions	<p>Jack length: 17.5 inches (445 mm).</p> <p>Jack diameter, closed: 2.75 inches (69.9 mm).</p> <p>Pump: 27 x 7 x 6 inches (686 x 178 x 152 mm).</p> <p>Indicator: 11 x 9 x 7 inches (279 x 229 x 178 mm).</p>
Weight	<p>Jack: 33 pounds (15 kg).</p>

	Pump: 33 pounds (15 kg).
	Indicator: 11 pounds (5.0 kg).
	Twin Hose & Electric Cable: 76 pounds/100 feet (35 kg/31 m).
Materials	<p>Goodman Jack: Heat treated 17-4 PH stainless steel.</p> <p>Indicator Case: Aluminum.</p> <p>Cable: Six conductors, shielded with waterproof polyurethane jacket, 0.35 inch; (8.9 mm) O.D.</p> <p>Hydraulic Hose: Neoprene jacket over double steel spiral braid.</p>
Electrical Connectors on Indicator	<p>Power: For connecting AC or DC power cable to indicator.</p> <p>Transducer: For connecting electrical cable from sensor to indicator.</p>
Fuses	<p>The system has one fuse located on the printed circuit card behind the indicator panel.</p> <p>Internal DC (F1): 1 amp.</p> <p>External DC (F2): 2 amp.</p> <p>AC Charge (F3): 0.25 amp.</p>
Digital Voltmeter	The visual display is provided by the digital voltmeter which reads the output from the LVDTs. The voltage is indicated on a 3-digit display. Accuracy of the voltmeter is ± 0.0002 .
Switch	<p>Power - On/Off: Turns system power on/off.</p> <p>Battery Test: Displays battery voltage on “far” DVM. To check the battery, rotate the control switch to “Batt. Test Position”. The reading (x 10) should be above 6 volts for a fully charged battery. Do not operate instrument when battery voltage is below 5.5 volts.</p>
Recharging the Battery	Connect the power cable to a suitable 110 V, 60 Hz outlet. The battery will charge fully overnight when power switch is in the OFF position.
Operating Time	With the batteries fully charged, the indicator will operate for eight hours at room temperature.

Setting Up

Hydraulic Connections

Attached to the jack are two short hydraulic hoses with self-sealing couplings. The shorter hydraulic hose is the expansion pressure line for the jack. The longer hydraulic hose is for the retracting pressure line and to close the jack. Hydraulic hoses, pressure gauge, T-coupling, and pump all have self-sealing couplings with dust caps. These components remain filled with oil when disconnected. When the jack, hoses and pump are disconnected, cover all connections with dust caps.

It is important to inspect the inside of the female coupling to assure that the stainless washer and sealing grommet are in place before connecting and after disconnecting. Oil leakage from the hoses when the jack is downhole can be very troublesome and could prevent successful removal of the jack.

1. Connect the T-coupling to the “Extend” port on the pump.
2. Connect the pressure gauge to the T-coupling.
3. Connect one hose to the T-coupling, and the other end to the “short” hose on the jack.
4. Connect the second hose to the “Retract” port on the pump, and the other end to the “long” hose on the jack.
5. Tighten threaded sleeve on all connections finger tight.

Electrical Connections

The electrical connection of LVDT cable to the jack is waterproof and the two mating halves of the connector are sealed with an O-ring.

1. Clean the O-ring and the mating surfaces, then carefully match the keyway and pins, and push the two halves of the connector together.
2. Tighten the nut by hand, then use wrench to tighten slightly more. Over-tightening can damage O-rings.
3. Connect the AC power cord of the indicator to the “Power” receptacle on the panel of the indicator and to the AC source, if available. If necessary, the indicator may be operated from a 12-volt DC source (truck battery) using the power cable with alligator clips on one end. The connector on this cable is plugged into the same receptacle as for AC power on the indicator panel.

Mechanical Connections

The integral mechanical coupling on the jack consists of an 8 inch (203 mm) length of BX flush-coupled casing with internal threads (8 threads per inch). By means of this coupling, the jack should be attached to BX-casing for inserting into the borehole. This system gives maximum protection to the jack, hoses, and cable while inserted in the borehole, and may also be used for orientation of the jack.

Other types of protective casing may also be used instead of BX casing; however, it must be “flush joint” to provide internal clearance for the two hydraulic hoses and electrical cable. NQ drill rod, which is a flush-joint type, is commonly used for drilling the hole, and may be more readily available than BX casing. The NQ drill rod, which has 3 threads per inch, is faster and easier to couple and uncouple than BX casing (8 threads per inch). If NQ drill rod is used, a sub will be needed to connect to the jack. The sub should have male BX threads (8 per inch) and female NQ threads (3 per inch) for a flush joint.

The BX casing, in 5 foot (1.5 m) lengths, can be pre-coupled to 10 foot (3.05 m) lengths, depending on the number to be used. The hydraulic hoses and electrical cable are threaded through each section of casing. Make sure all dust caps are in place when this is done. If the hose and cable are long enough, all of the casing to be used may be threaded on the hose and left on the ground until needed, eliminating the necessity for coupling and uncoupling the hoses. Enough slack must be left in the hose at the borehole end to allow insertion into the boring. After threading, make hydraulic and electrical connections as described.

1. Screw the first section of BX casing onto the jack. Place a chalk mark on the upper end of the casing to identify orientation of the jack.
2. Insert the jack into the borehole and support with a portable pipe vise or casing clamp.
3. Lift the next 10 foot (3.0 m) section of casing above the borehole and screw into first section. Place a mark on the upper end for orientation of the jack corresponding to the mark on the first section of casing.
4. Lower both sections into the borehole. Attach the portable pipe vise to support the jack in the borehole. Use pipe wrenches for handling the jack.

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5. It is feasible to handle 20 feet (6.1 m) of casing by hand (weight of flush coupled BX casing is 57 pounds per 10 foot section, or 8.5 kg/m). For more than 20 feet (6.1m) of casing, it will be necessary to use a drill rig or similar system to handle the load.
 6. Use care to avoid bending the hydraulic hose around the sharp end of the casing. Minimum bend radius for the hydraulic hose is four inches (100mm).

Field Testing the System

After all hydraulic and electrical connections have been made, check the jack to make sure it is operating before inserting it in the borehole.

A piece of pipe with an inside diameter of three inches (76.2 mm) is a useful device for field checking the instrument. If the pipe is steel, with a wall thickness over one inch, the hydraulic pressure system may be checked for operation and leakage up to 10,000 psi (70 Mpa).

1. Switch the indicator “ON”. The two illuminated displays for the LVDT’s should read near zero when the jack is not connected. With the jack connected, the instrument will read the \pm deviation from the 3.000 inches (76.2 mm) jack diameter.
2. Switch to “Battery Test” if operating on an internal battery. For a fully charged battery, the reading on the “Far” LVDT display should be greater than 6 volts. Do not operate instrument if the battery voltage is less than 5.5 volts. Switch back to “ON”.
3. Observe reading for fully closed position of the jack. The reading of diameter deviation should, theoretically, be -0.250 inch (6.35 mm) with the jack closed. However, because of the non-linearity of the LVDT, the actual reading will be less, as indicated on the calibration curve. Dual meters on the panel give readings for each LVDT, “Near” and “Far”, simultaneously.
4. Set the pump valve to “Extend”. Apply pressure to the jack by operating the pump handle. Observe the readings on the indicator as the jack pressure plate is extended. When the readings are approximately ± 0.000 inch, the diameter of the jack should be approximately 3.00 inches (76.2 mm) measured with calipers or micrometer.

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5. When the jack diameter is greater than three inches (76.2 mm), the deviation readings will have a positive (+) polarity sign displayed. Check the deviation readings and rough measurements of jack diameter against the calibration curve provided.
 6. Extend the jack to almost fully open position, as indicated on the jack calibration sheet. Do not apply any pressure when movable plate reaches its limit of travel. If pressure is applied while jack is in fully extended position, the pressure plate will bend and the piston O-rings will be forced out of position and cause severe wearing of moving parts of the jack.
 7. Observe meter deviation readings for both LVDTs. Check with calibration sheet. The two LVDT readings obtained should agree within 0.02 inches (0.50 mm).
 8. Set pump valve to “Retract” position. Apply retracting pressure to the jack by operating the pump handle. As the jack closes, observe the meter indication. Verify readings when jack is closed.

Measurements in Hard Rock

Instructions for the Hard Rock Goodman Jack

A typical Field Data Sheet is provided at the end of this chapter.

1. Insert jack into borehole to the test depth.
2. Set indicator power switch to “ON”.
3. Set pump valve to “Extend”. With pump handle, apply pressure to the jack until the jack expands against the sides of the borehole.
4. Observe the meter readings while the jack pressure plate is being extended.

In an NX borehole, the jack should contact the sides of the hole when the meter indicates approximately zero. Zero on the meter corresponds to 3.00 inches (76.2 mm) diameter of the jack across the pressure plates.

5. When contact with the side of the borehole is made, increase the pressure until the pressure gauge indicates a value equal to the first increment. Ten increments are usually sufficient. Therefore, when operating in hard rock, 1000 psi (7.0 Mpa) may be a suitable value.
6. Observe the meter reading for both LVDTs. The meter reads directly in inches (mm) deviation from 3.00 inches (76.2 mm) (nominal borehole diameter). The least reading is 0.001 inch (0.01 mm).
7. Compare each meter reading with the calibration sheet to determine the actual value (interpolating between the 0.020 inches (0.5 mm) increments listed on the calibration sheet).
8. Apply increasing pump pressure until the second increment is reached, equal to 2000 psi (14 Mpa). Observe each meter reading and compare with the calibration sheet as noted above. It may be necessary to apply a small amount of pressure with the handle in order to hold the pressure constant. This small leakage may occur within the pump. A constant pressure should be maintained while taking the readings.

Note In order to evaluate creep in the material, hold the pressure constant for a suitable length of time, approximately five minutes, and record LVDT readings every minute, or other suitable period.

Observe the difference between the readings for each LVDT, and determine the actual difference from the calibration sheet. Any difference means that the movable jack plate is tilting due to discontinuity in the borehole wall, or a non-uniformity in the strength of the material. This could mean that the jack is located at a transition zone. When the actual difference reaches approximately 0.020 inches (0.50 mm), excessive wear on the guide pins and LVDT adapter may occur. When tilting greater than this takes place, it is recommended that the test be discontinued and the jack moved up or down to another location where the material may be more homogenous and uniform.

9. Increase pressure and make readings of displacement versus pressure. Sufficient increments should be taken to insure an accurate plot of load versus displacement.
10. When sufficient readings are obtained, reverse the procedure, reducing pressure by carefully cracking the valve on the pump. This allows oil to be bled back into the pump reservoir under control. Stop and make readings of displacement and pressure at sufficient increments to observe the rebound characteristics of the material.

Repositioning the Jack

The jack must be completely closed before you move it. If it is not closed, the pressure plate may be damaged or the jack may become stuck in the borehole.

- The movable plate on the jack can be retracted to the closed position by setting the pump valve to “Retract” and operating the handle. When the jack reaches the closed position, an increase in pressure on the pump handle will be felt. Also, when the pump valve is switched to neutral, an audible squeal will occur as the oil under pressure escapes back into the reservoir.
- Another method to determine this is to count the number of pump strokes. Usually 15 to 20 strokes are required. Relieve all pressure by switching to the “Extend” position momentarily, then back to neutral.
- A more satisfactory method is to observe the displacement reading on the displacement indicator and simply pump until the meter readings are within approximately 0.010 inches (0.25 mm) of the “Closed” position readings found on the top line of the calibration sheet.

Measurements in Soft Rock

Instructions for the Soft Rock Goodman Jack

The three-piston Goodman Jack is designed for use in softer rock. Its pressure efficiency is approximately 50% of the Model 52101 Jack, as given in the specifications.

In some cases, it may be necessary to adapt a lower-range pressure gauge and connect it to the T-coupling at the pump.

In other cases, it may be necessary to modify the test procedure to measure the consolidation properties of the material. To do this, apply a suitable increment of pressure, say 100 psi (0.7 Mpa), when using a 1,000 psi (7 Mpa) gauge.

1. Hold the pressure constant with the pump handle, recording the meter indication of displacement for each LVDT every minute. Continue until the displacement becomes constant to within some arbitrary value, say 5%, of the initial displacement.
2. Apply the next increment of pressure and repeat the readings.

The plot of final deflection for each increment plotted versus pressure becomes the consolidation curve. Some variations may be necessary in the foregoing as determined for the material being tested.

In the drilling of the boreholes in soft rock, it must be remembered that the Goodman Jack is designed to operate in NX holes; that is, 3 inches (76.2 mm) diameter, nominal. The jack pressure plate extension is limited to 3200 inches (81.2 mm) diameter, and this means that the hole must be drilled with reasonable precision in order for any data to be obtained. This requirement is more important in soft rock because the material consolidates more under the jack pressure plates, producing more displacement. This means that the allowance for oversize boreholes is less than for hard rock holes. The situation in soft rock holes is more of a problem because the hole tends to be worn oversize by whipping action of the rods and washing action of the drilling water carrying the cuttings. For this reason, planning the drilling procedure should be done with care and with expectation of reasonable precision in the diameter of the completed boreholes.

Some types of soft rock may tend to disintegrate or soften whenever exposed to the water used in drilling. In this case, and when

the borehole is oversize, it will be necessary to run the Goodman Jack tests immediately after coring every 10 feet (3.0 m) of borehole. The system is readily adaptable to this method of operation. Depending on the type of drill rig being used, as much as 40 to 50 feet (12 to 15 m) of BX casing attached to the Goodman Jack may be stood vertically, tied to the mast, while drilling the next 10 feet (3.0 m). Other sections are readily added and removed, threading them over the hoses. Extra hose facilitates the usage and handling of BX casing under these circumstances.

In situations where the Goodman Jack tests must be made immediately following the coring operation, then the planning of the test program must include allowance for the additional time needed for in and out of the borehole with the jack and the protective BX casing.

Care must be used at all times to protect the hose when it is bent over the sharp edge of the casing.

Repositioning the Jack

The jack must be completely closed before you move it. If it is not closed, the pressure plate may be damaged or the jack may become stuck in the borehole.

- The movable plate on the jack can be retracted to the closed position by setting the pump valve to “Retract” and operating the handle. When the jack reaches the closed position, an increase in pressure on the pump handle will be felt. Also, when the pump valve is switched to neutral, an audible squeal will occur as the oil under pressure escapes back into the reservoir.
- Another method to determine this is to count the number of pump strokes. Usually 15 to 20 strokes are required. Relieve all pressure by switching to the “Extend” position momentarily, then back to neutral.

Data Reduction

The result of Goodman Jack testing in a borehole of diameter d is a graphical plot of applied pressure Q_h versus diametral deformation u_d . Young's Modulus will be computed as the tangent modulus along the slope of the linear portion of this plot of the field data.

From page 16 of the reference paper by Goodman, Van, and Heuze:

$$E = 0.86K(v) \times \frac{\Delta Q}{(\Delta u_d)/d}$$

Where:

ΔQ = incremental change in plate pressure, psi or Mpa

Δu_d = incremental change in displacement, inches or mm

d = borehole diameter, inches or mm.

$K(v)$ = Jack constant, depending on Poisson ratio

For a jack efficiency of 93%, the applied hydraulic pressure Q_h is greater than the plate pressure. For the Hard Rock Jack, $Q=0.93Q_h$ and for the Soft Rock Jack, $Q=0.55Q_h$.

$K(v)$ is a factor dependent on the Poisson's ratio for the rock being tested and is listed in the Goodman, Van, and Heuze (1968) reference.

The reference in Appendix A recommends that the term T^* be adopted instead, for full contact of the jack. T^* values are listed in Table 2 on page 207 in Appendix A. Also, the formula above should be altered to be an expression for the calculated apparent modulus of deformation, E_{calc} , as follows:

$$E_{calc} = 0.8(d) \times \frac{\Delta Q_h}{\Delta U_d} \times T^* \quad \text{Hard Rock Jack}$$

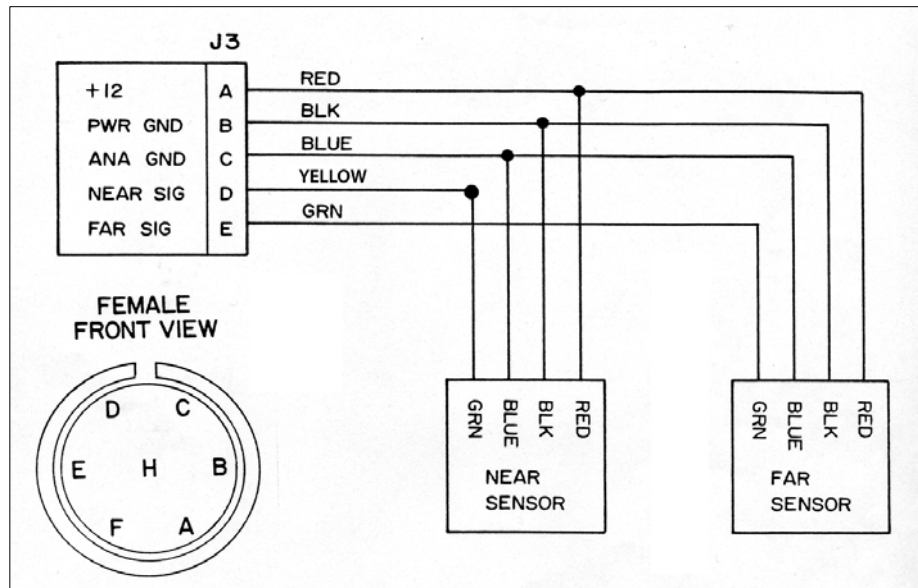
$$E_{calc} = 0.47(d) \times \frac{\Delta Q_h}{\Delta U_d} \times T^* \quad \text{Soft Rock Jack}$$

These equations may or may not be valid under all conditions. It is recommended that a study of Appendix A and the references be made to verify or modify the value according to the field conditions present in-situ.

Maintenance

Electrical Connections

After the jack has been used in a borehole, carefully wipe the connector on the jack dry before separating the two halves. This will prevent moisture entering the contacts. At all times when the electrical connectors are separated, make certain the protective caps are in place. The schematic below shows wiring for the sensor.



Hydraulic Connections

Each hydraulic connection has a male or female self-sealing quick-connect coupling and corresponding dust cap. Whenever connections are separated, these dust caps should be attached. This is especially important during field operations and when threading the hose through BX casing. Also, make sure the rubber grommet and steel washer are in place in each coupling, otherwise oil leakage will take place.

Hydraulic Oil

The hydraulic oil used in this system is type HF-101, distributed by Enerpac Division, Blackhawk Industrial Products Company. The pump has a reserve supply which can be checked with the dip stick at the rear.

Whenever refilling the pump with oil, you should attempt to remove all air. Elevate the hose so all air goes to the high end and bleed the air while under pressure applied by the pump. Two pipe plugs at the far end of the Goodman Jack body may be removed to bleed air from the two pressure circuits in the jack.

O-Ring Replacement

O-ring inspection and replacement should be included as part of a preventative maintenance program. The frequency of replacement will vary depending on the amount of service and conditions in the borehole to which the jack has been exposed.

O-rings should also be inspected and possibly replaced when excessive leakage is detected. However, check that the problem is not in your hose connections before replacing O-rings.

To replace O-rings you must disassemble the Jack.

The table below lists the O-rings used in the Jack.

O-Rings used in Goodman Jack						
Location	Number	Part	ID	OD	Thickness	Hardness
Piston, Soft Rock Jack	3	06100724	1.734 in (44.04 mm)	2.012 in (51.10 mm)	0.139 in (3.53 mm)	90 Durometer
Piston, Hard Rock Jack	12	06100721	1.421 in (36.09 mm)	1.699 in (43.15 mm)	0.139 in (3.53 mm)	90
LVDT Housing Bore, Bottom Body Half	2	06100124	0.984 in (24.99 mm)	1.262 in (32.05 mm)	0.139 in (3.53 mm)	70
Retract Piston	2	06100122	0.859 in (21.82 mm)	1.137 in (28.88 mm)	0.139 in (3.53 mm)	70
Stem of Retract Piston	2	06100054	0.549 in (13.94 mm)	0.755 in (19.18 mm)	0.103 in (2.62 mm)	70
Under LVDT Housing Flange	2	06100022	0.989 in (25.12 mm)	1.129 in (28.68 mm)	0.070 in (1.78 mm)	70
LVDT Housing Stem	2	06100058	0.799 in (20.29 mm)	1.005 in (25.53 mm)	0.103 in (2.62 mm)	70
Cap Over LVDT Adjusting Screw	2	06100015	0.551 in (14.00 mm)	0.691 in (17.55 mm)	0.070 in (1.78 mm)	70
Electric Connector	1	06100056	0.674 in (17.12 mm)	0.880 in (22.35 mm)	0.103 in (2.62 mm)	70

Remove Plate

1. Place jack horizontally with bottom plate down on a table; or better, in a suitable vise. Protect jack from steel jaws with a rag.
2. Connect hoses and cable to jack, pump, and electronic read-out (indicator).
3. Expand jack to fully expose six screws that hold collar to jack. Remove screws and collar. Hoses and cable must be temporarily disconnected to remove collar.
4. Reconnect hoses and cable. Remove end shields.
5. Remove bolts at each end of jack on top plate holding the

retract pistons. These pistons are spring loaded when jack is expanded. If necessary use the special key to keep pistons from rotating while removing bolts with Allen wrench. The top plate is now free to be removed.

6. Remove the top plate carefully, keeping plates parallel during removal. Use electronic readout to note plate parallelity. Cautiously pump from “expand” position and lift by hand, or by using brass dowels to remove plate. If plates do not remain parallel, the LVDT housings may jam, and cause the fastening screws to loosen and create a potential for water leakage into the LVDT’s.

Remove Pistons

1. Using this careful pumping procedure, the 12 or 3 pistons will lift toward their maximum position. Further expansion may be accomplished by pumping until one piston O-ring is exposed. Keep the work area very clean since the oily surfaces pick up any debris and dust it comes into contact with.
2. Remove pistons. Remove O-rings by hand. Wipe clean all surfaces and O-rings. Inspect pistons and O-rings under a magnifying glass for damage. O-rings should be perfectly round in cross section without scratches or cuts. If metal surfaces on pistons or cylinders are damaged, hand lapping or machine shop refitting may be needed. Contact Slope Indicator.

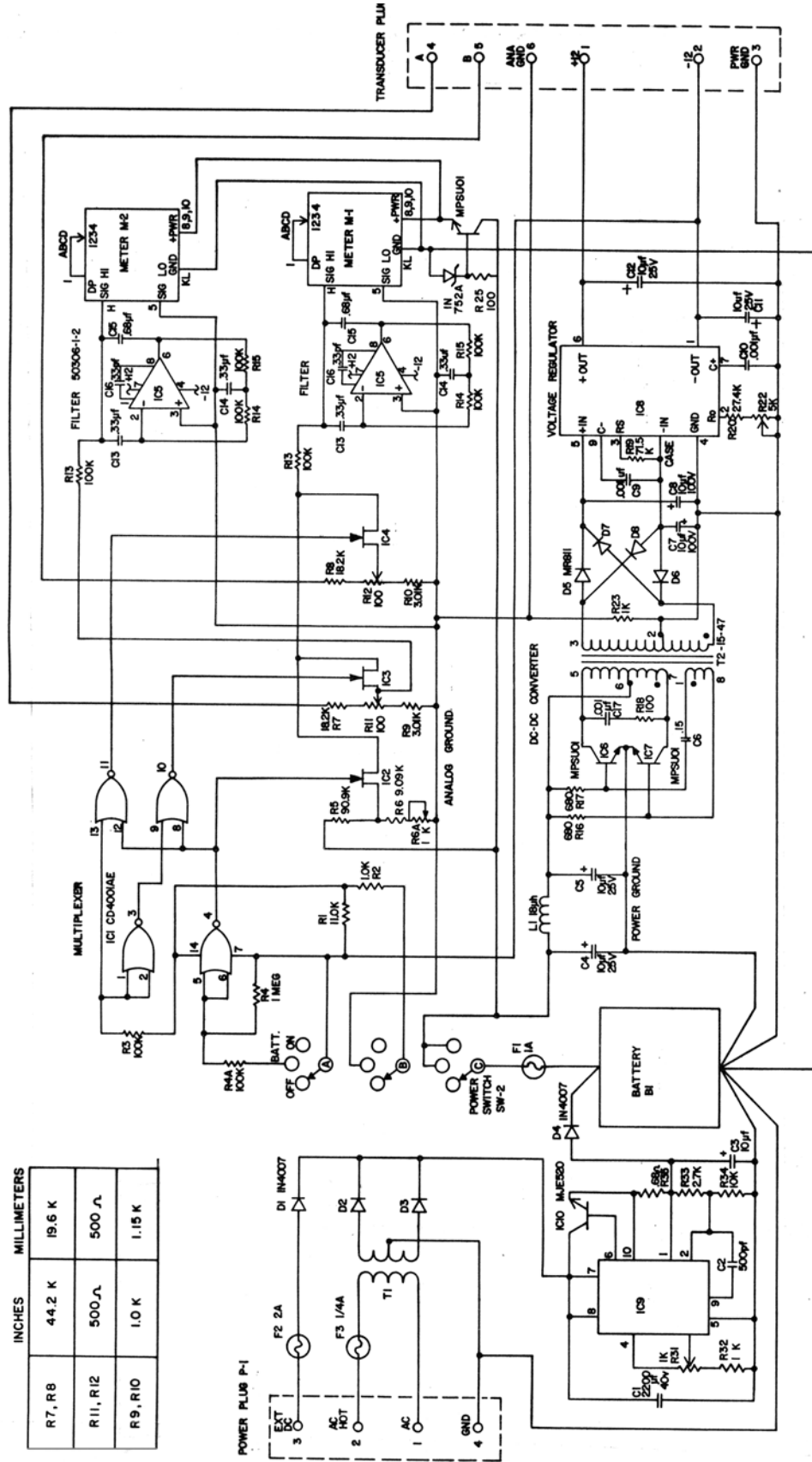
Position the O-Rings

1. Replacement O-rings should be coated with special O-ring lubricant. Place each O-ring into the groove on each piston by hand. Be careful not to scratch the O-ring surface. Scratches would be a source of oil leakage.
2. Insert piston into cylinder. The top edge of the cylinder is chamfered to aid the O-ring into the cylinder without being cut or scratched. Use a blunt wooden stick or plastic ruler (some suitable object which won’t cut or scratch the O-ring) to aid in pushing O-ring into chamfered space. Apply a little pressure by hand while pushing the O-ring into piston.
3. After positioning, apply a firm hand pressure to top of piston and force it into the oil filled cylinder. Pump should be in neutral position. Observe the O-ring while pushing, making sure that O-ring is exposed evenly all around the piston. A slight easing of resistance will be felt the moment the piston O-ring goes into the cylinder. Push piston in at least half way, or more, to keep it from popping out when other pistons are inserted. Repeat procedure for all pistons.

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- Replace the Plate
1. Wipe all surfaces clean before plate reassembly.
 2. Carefully put top plate back into position using the two guide pins. Turn on indicator and observe plate parallelity. Make sure the pins do not bind.
 3. Attach bolts holding the retract pistons. It is usually necessary to push retract pistons in by hand to engage bolt thread. It may also be desirable to replace O-rings on retract pistons before reassembly. Tighten the bolts gradually, moving wrench from one bolt to the other, keeping plates as parallel as possible.
 4. Apply pump pressure to retract pistons initially to bring jack back to fully closed position. DO NOT over pressure. Observe plate parallelity at all times.
 5. Place jack vertically with bottom end up. Remove 5/8 inch vent plugs to remove air accumulated in the jack. Alternately pump from expand and retract position to remove air. After air bubbles have ceased to come out, screw vent plugs back in. Pump should be in neutral position. Replace Teflon sealing tape on plugs and clean old tape carefully from all threads before reassembly. Make sure plugs are on very tight.
 6. Recheck all bolts for retract pistons, and guide pins for tightness.
 7. Replace end shields and collar. The jack is now ready for calibration and/or testing.

Displacement Indicator

This is the schematic for the displacement indicator.



INCHES	MILLIMETERS
R7, R8	44.2 K
R11, R12	500 Ω
R9, R10	1.0 K
	1.15 K

Calibrating the Goodman Jack

Introduction Goodman Jacks are normally calibrated at the factory, using the following procedure. To conduct the calibration, you must keep the loading plates in a perfect parallel position at each calibration point, and you must have two dial gauges mounted to the base of the jack with special brackets.

The gauges should have a minimum travel of 1 inch (25 mm) and be provided with special mounting brackets. This assembly clamps to the base plate. Position the dial gauge over the center of the top bearing plate.

You can find a sample calibration form at the end of this chapter.

- Zero Point Adjustment**
1. Mount dial gauges on jack so that gauges touch top bearing area about 0.6 inches (15 mm) from ends. Make sure all gauge mounts are tight.
 2. Close jack completely and adjust dial gauges to mid-range.
 3. Using micrometer, measure diameter at each end of loading plates. Adjust gauges by turning dial face to difference from 3 inches (zero point).
 4. Adjust plates by pumping and assisting with brass (soft metal) hand dowels until plates are parallel.
 5. Check plate diameter again with micrometer. Repeat steps (c) and (d) until micrometer indicates 3.000 inches (76.2 mm) at both ends.
 6. Reset dial gauges to mid-range with pointer vertical if needed. Make sure that they have at least 0.250 inches (6.35 mm) travel in both directions.
 7. With the special T-handle wrench provided, remove the two sealing caps from the jack body. This exposes the LVDT core “zero” adjusting screws. Loosen the jamb nut with the 5/16 inch box wrench provided and turn the LVDT core with a screwdriver until the corresponding displacement indicator reading is zero. Tighten the jamb nut. Check zero again. Repeat if needed. When zero setting is satisfactory, replace the sealing cap. Repeat procedure for the other LVDT. Measurements should be within 0.001 inches (0.02 mm).

Scale Factor Adjustment

1. After the zero points are set, extend and adjust the jack to a +0.100 inch (+2.50 mm) reading on the dial gauges. Note the displacement indicator readings.
2. Carefully remove the front panel from the indicator box without disturbing the battery connections. On the back side, locate the variable resistance potentiometers on the printed circuit board. They are marked "Near" and "Far".
3. Adjust the readout trim pots so that both displays read +.100 inches (+2.50 mm). Fully close jack and re-expand to 3.000 inches (76.20 mm) and recheck the zero. Continue the expansion to 3.100 in. and recheck the readings. If both readings are correct, the jack is ready for calibration.
4. Fully close the jack and commence expanding in increments of 0.020 inches (0.50 mm). Record the readings at each point throughout the available range.

The above procedure is designed to linearize the output of LVDT's through the most useful range of expansion. Accordingly, at positions below 3 inches and above 3.100 inches it is unlikely that the readings obtained will agree with the indicated position, and this need not cause concern.

5. Remove dial gauges. The calibration is finished.

Goodman Jack Calibration

Jack Serial Number:		Calibrator:		Date:	
Indicator Serial Number:			Length of Electrical Cable:		
Reading of Near LVDT	Reading with Scale Factor Adj	Diameter inches / mm	Reading of Far LVDT	Reading with Scale Factor Adj	Diameter inches / mm
		2.75 / 69.85			2.75 / 69.85
		2.78 / 70.70			2.78 / 70.70
		2.80 / 71.20			2.80 / 71.20
		2.82 / 71.70			2.82 / 71.70
		2.84 / 72.20			2.84 / 72.20
		2.86 / 72.70			2.86 / 72.70
		2.88 / 73.20			2.88 / 73.20
		2.90 / 75.70			2.90 / 75.70
		2.92 / 74.20			2.92 / 74.20
		2.94 / 74.70			2.94 / 74.70
		2.96 / 75.20			2.96 / 75.20
		2.98 / 75.70			2.98 / 75.70
		3.00 / 76.20			3.00 / 76.20
		3.02 / 76.70			3.02 / 76.70
		3.04 / 77.20			3.04 / 77.20
		3.06 / 77.70			3.06 / 77.70
		3.08 / 78.20			3.08 / 78.20
		3.10 / 78.70			3.10 / 78.70
		3.12 / 70.20			3.12 / 70.20
		3.14 / 79.70			3.14 / 79.70
		3.16 / 80.20			3.16 / 80.20
		3.18 / 80.70			3.18 / 80.70
		3.20 / 81.20			3.20 / 81.20

References

For more detailed information on theory and application of the Goodman Jack, derivation of the basic formula and interpretation of data, please refer to:

- “The measurement of Rock Deformability in Bore Holes”, by R.E. Goodman, T.K. Van, and F.E. Heuze, 10th Symposium of Rock Mechanics, University of Texas, May 1968.
- “Plate-Bearing and Borehole-Jack Tests in Rock: A Finite Element Analysis”, by F.E. Heuze and A. Salem, Proceedings 17th Symposium on Rock Mechanics, Salt Lake City, Utah, August 25-27, 1976.
- “An analysis of the Goodman Jack”, by W.A. Hustrulid, University of Utah, Salt Lake City, Utah, 1976.
- “A Comparison of Rock Deformability Measurements by Petite Sismique, The Goodman Jack and Flat Jacks”, by Z.T. Bieniawski, Pennsylvania State University, Proceedings of RETC, Atlanta, Georgia, 1979.
- “Suggested Method for Estimating the In-Situ Modulus of Deformation of Rock Using the NX-Borehole Jack”, by Heuze, F.E., ASTM Geotechnical Testing Journal, GTJODJ, Vol.7, No. 4, Dec. 1984, pp 205-210.

Appendix A

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