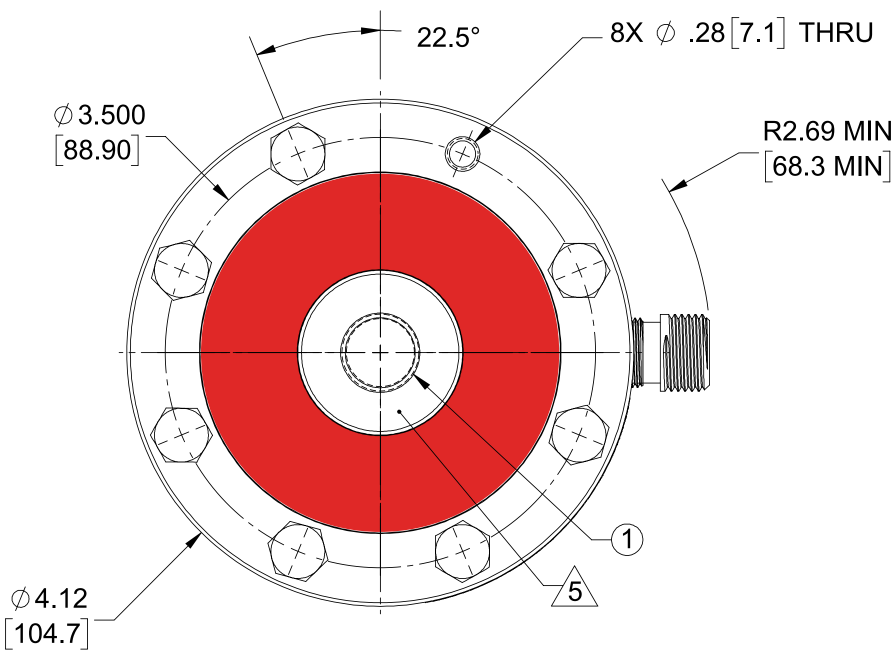
LOAD CELLS 401 GUIDE

WEIGHING & TESTING INDUSTRY APPLICATION DETAILS



Interface®, Inc.
7401 Butherus Drive
Scottsdale, Arizona 85260
480.948.5555 phone
contact@interfaceforce.com
http://www.interfaceforce.com

Building upon the foundation established in Interface Load Cells 101, 201, and 301 Guides, the 401 Guide is an advanced resource that delves deeper into the intricacies of load cell utilization within complex industrial settings. Authored by our team of industry-leading force measurement specialists, the 401 Guide empowers test engineers and measurement professionals with the comprehensive knowledge required to navigate the demanding world of multi-cell systems and specialized weighing and testing applications.

This practical handbook is your key to unlocking the full potential of your load cell systems. It provides detailed explanations, illustrative figures, and in-depth scientific insights.

Embark on a comprehensive exploration of multi-cell configurations. We meticulously dissect critical aspects like load equalization and corner adjustments. For applications requiring exceptional stability, the concept of moment-compensated platforms is thoroughly examined, providing the knowledge of how this impacts results.

Interface's 401 Guide explores the intricacies of single- and two-cell systems, equipping you with the expertise to confidently navigate these fundamental yet essential setups. We venture beyond basic configurations, investigating the use of load cells in conjunction with pipes and conduits, checking rods, and unveiling methods to measure precisely the forces acting along these pathways.

Delving into parallel connections, the guide meticulously explores the art of effectively combining multiple load cells to achieve the desired capacity and performance characteristics. It also details universal compression cells, providing insights into these versatile workhorses of the force measurement industry.

The Interface Load Cells 401 Guide serves as your trusted companion, providing advanced knowledge and practical strategies to unlock the full potential of your load cell systems.

Your Interface Team

TABLE OF CONTENTS

WEIGHING AND TESTING INDUSTRY APPLICATION DETAILS

MULTI-CELL STATIC OR WEIGHING APPLICATIONS

Compression cells are widely used for weighing applications because they are less expensive and in some cases have slightly lower errors. *Figure 1* shows a typical application. The load cell with base is mounted on the stud which is permanently affixed in the bottom plate. This gives the cell added protection against any uneven surface under the bottom plate which might affect the calibration of the cell.

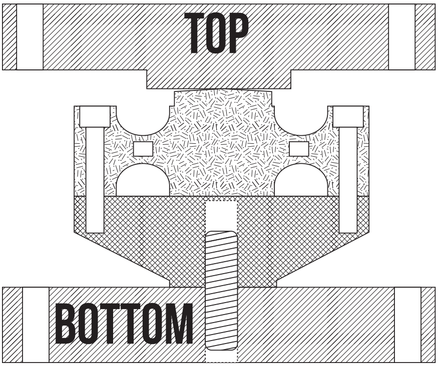


Figure 1. Top Plate, Cell with Base, Bottom Plate

The load cell's load button is hard anodized or heat-treated to ensure a hard surface. The load bearing surface of the top plate must be heat treated to increase its hardness. Cold rolled steel or similar material is not appropriate, because the surface will soon gall and become useless. Also, the finish of both the top plate's bearing surface and load cell's load button should have 32 µinch or smoother surface roughness to ensure that galling will not occur.

The configuration of *Figure 1* is widely used because the cell with base can be removed as a complete assembly by screwing it off of the bottom plate's stud. When it is replaced, the original factory calibration of the new cell can be preserved, because the base protects the load cell against any unevenness in the surface facing the bottom of the base.

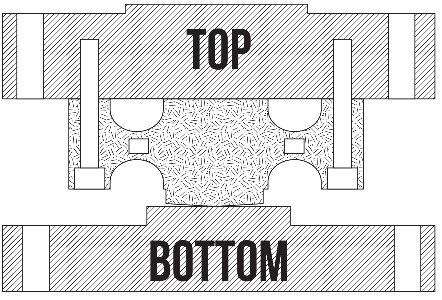


Figure 2. Upside Down Cell Mounted on Bottom Plate, Bearing on Upside-Down Top Plate.

The configuration of *Figure 2* is used in situations where the bottom surface of the hopper leg that bears on the load cell/bottom plate assembly can be machined flat and smooth. This allows the load cell to be mounted directly on the bottom plate, without an intervening base, thus saving the cost of a base. Although conceptually simpler, this configuration requires that the bottom plate be installed at the factory so that the assembly can be calibrated. This configuration also protects the diaphragm surface of the load cell from being subjected to standing water in installations having water misting or splashing.

The majority of compression cell applications are multiple-cell installations. The number of cells may run anywhere from 3 cells on a simple weighing platform to 16 cells on a long truck scale.

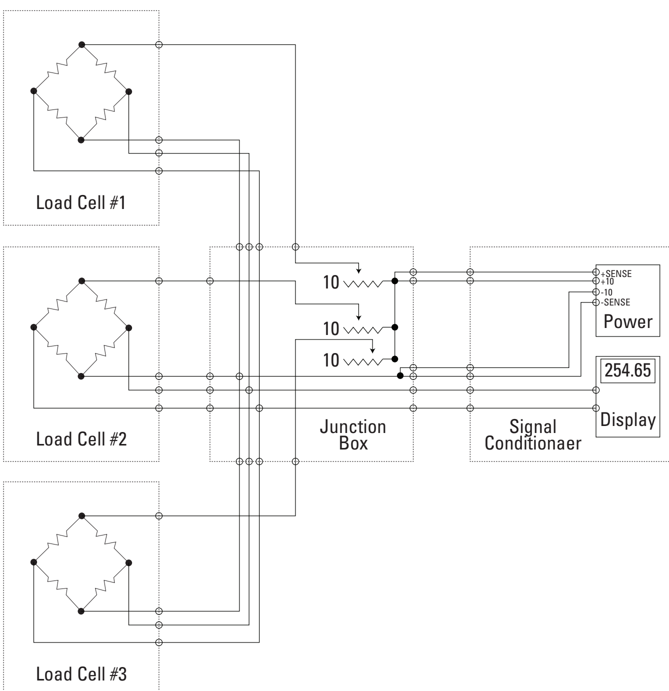


Figure 3. Typical Three-Cell Wiring Diagram

In every case, the accuracy and repeatability of the system will be improved by following these simple rules:

1. Use a junction box which has balancing adjustment potentiometers.
2. Buy load cells which have "Standardized Output," so that they can be "corner adjusted" either in the factory or when they are installed.
3. In any installation having more than three load cells, shim the low corner of each group of 4 cells until all the cells are sharing the load equally within 10%.
4. Perform a corner adjustment after the cells are shimmed, if it was not done at the factory.

EQUALIZING THE LOADS IN MULTIPLE-CELL SYSTEMS

When designing the mechanical mounting of the cells in a multiple-cell system, provisions should be made for the leveling adjustment necessary to equalize the loading of the cells among all the "corners" of the system. (In this context, all the cells in a multicell system are called "corners," even though some of them may be on sides, between corners.) It is advantageous that all the cells operate at the same point on their operating curves, by being equally loaded, in order to achieve maximum system accuracy.

Everyone has had the experience of sitting on a four-legged chair which has one slightly short leg, and getting the feeling of rocking back and forth with one or the other leg always off the floor. Although we think that our weight is being carried by three of the four legs, in truth almost all of the weight is sometimes on only two of the legs. The same effect can be seen on a multiple-cell system that has been improperly shimmed.

CAUTION:

In an improperly equalized four-cell system, it is possible that the total load could be carried momentarily by two diagonally opposite load cells, which would be almost certain to overload the cells.

The "rocking chair" effect will be more or less pronounced, depending on the stiffness of the framework or structure which transmits the load to the cells.

For example, we can construct a very stiff system by making a tank out of a thick-walled steel pipe that four feet in diameter with a flat bottom welded inside it part way up from the bottom, as in *Figure 4*. The bottom edge of the pipe is prepared by having hard inserts welded into it to match the locations of the load buttons on the load cells, and the inserts are carefully ground to a planar surface. The four load cells are mounted on a very thick, stiff steel plate that has been ground as flat as possible.

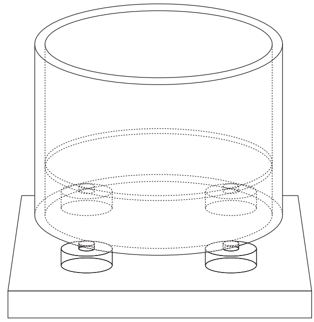


Figure 4. Example of Stiff Tank and Stiff Support

As the pipe is slowly and carefully lowered onto the cells, we find to our dismay that two diagonally opposite cells are taking much more load than the other two cells. This is happening because the full scale deflection of the load cells is only a few thousandths of an inch, and it is too costly, if not impossible, to grind the surfaces of the plate and the tank that flat over such a large span to that close of a tolerance.

If we had any intention of shimming the cells to equalize the loading, we would need to use shims that are only about ⅕ the thickness of a piece of paper. Such a task would take days to accomplish. In addition, distortion of the tank by temperature gradients (uneven changes in temperature) in the tank when the sun shines on it or when hot liquid is pumped into it would introduce dramatic changes in the careful job of shimming which we had just finished.

The important lesson to be learned from this example is that there needs to be some flexibility built into the design of the tank structure to make the shimming job easier and to reduce the effect on the cell loading caused by temperature gradients distorting the tank. *Figure 5* simulates a springy system by actually picturing springs under the legs, which makes it easier to visualize how a springy frame alleviates the shimming problem.

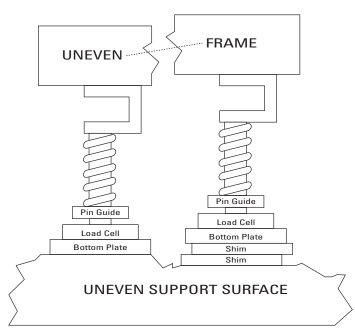


Figure 5. Shimming a Springy System

We can now calculate the effect of the addition of a shim which is 0.002” thick. Let’s assume a

10,000 lbf load cell with a deflection of 0.002" at full capacity, which gives it a stiffness of 5 million pounds per inch.

In the "stiff" case of *Figure 4*, adding or removing one shim only 0.002" thick would change the load on that cell by 5,000 lbf. It would thus be very difficult to adjust the loading on the cell in increments of 5% of full capacity. (The reader is left with the problem of figuring out why the change in loading is only ½ of the "expected" value.)

Now, let's assume that the springs in *Figure 5* have been chosen to have a stiffness of 50,000 pounds per inch, 1/100th of the stiffness of the load cells. When we first lower the frame onto the cells, the springs will alleviate much of the uneven loading on the cells. In addition, as we check the cells' outputs, we find that the addition of a shim of 0.002" thickness raises the loading on that cell by 50 lbf, well within the equalization increment of 5% of full capacity for which we are aiming.

Equalizing a tension system is a much easier task than shimming a compression system. The load cells will all be moment protected, either by the use of rod end bearings and clevises or by using flexible cable assemblies on each cell. It is then necessary only to insert a turnbuckle in one of the supports on a four-cell system, two of the supports in a five-cell system, or three of the supports in a six-cell system. Since one-, two-, or three-cell systems do not need physical shimming adjustment, they are obviously much easier to install, and are hardly affected by distortions due to temperature gradients in the support framework.

CORNER ADJUSTMENT OF MULTIPLE-CELL SYSTEMS

After the cells have all been equalized, an electrical corner adjustment will be needed on most systems unless it has already been done at the factory.

> *NOTE:*
> *Do not change any adjustments on a system which has already been calibrated at the factory. The factory calibration will be lost.*

Corner adjustment is accomplished as follows:

1. Apply power to the system and make sure that the excitation voltage is the specified value, when measured at the point of voltage sensing in the system.

2. Turn all the adjustment pots in the junction box to the zero resistance point.
3. Empty the vessel, tank, or hopper as much as possible.
4. Measure the output of all the load cells separately and record their values. This can be done by disconnecting only one wire, the +Out wire (green) for each cell in the junction box and reading the voltage between the +Out (green) and –Out (white) wires. (In special applications, the wire colors may be different. Check the installation documentation.)
5. Apply the largest weight within the capacity of the individual load cells as close to one cell as physically possible. Record the output. Repeat for each cell, using the same weight each time.
6. Calculate the incremental output (the difference between the loaded and unloaded readings) for each cell.
7. Note which cell has the lowest incremental output.
8. Apply the same weight again to the higher reading cells, and adjust each cell's output down to match the lowest cell, by adjusting that cell's pot.
9. Repeat the check again, starting at Step 5, on all except the lowest cell, and adjust as necessary to match the lowest cell.
10. Reconnect the wiring, and have the system calibrated using in-house procedures.

MOMENT COMPENSATED PLATFORM

In the same way that a load cell can have moment sensitivity (output variation for off-axis loads), a weigh platform can respond differently for loads which are not exactly on the center of the platform. In the case of *Figure 6*, where the three load cells are equally spaced around the bolt circle with radius *(R)*, if the outputs of the cells are corner adjusted properly, the weight indication of the platform will be the same for any location of a test weight. This fact would seem to be intuitively true, simply because of the symmetry of the load cell layout.

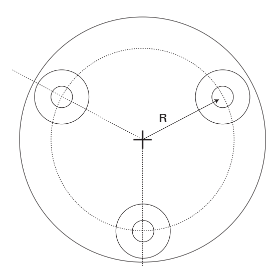


Figure 6. Plan view, Three Cell Platform

But, when we propose the layout of *Figure 7*, the lack of rotational symmetry strains our intuition, and we may struggle with the concept that the only criterion for a successful weigh platform is that the cells are corner adjusted. However, strict mathematical analysis of either system yields the same answer: corner adjustment alone is sufficient.

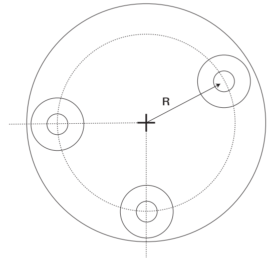


Figure 7. Variaton on Load Cell Layout

There may be a functionally logical reason for the arrangement of *Figure 7*, or even *Figure 76*. In many cases, the load may be applied from a particular edge or a motor/gear assembly may be mounted off-center, and the concentration of cells closer together tends to distribute the load between the three cells more evenly.

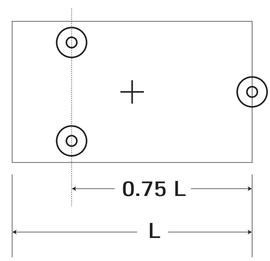


Figure 8. Rectangular Layout for End-Loaded Conveyor Frame.

The dimensions in *Figure 8* are correct for an evenly loaded conveyor frame where the loads are placed on the frame at the left end, on the line connecting the two cells. This arrangement gives more margin to protect the cells from overload. Incidentally, the load is equally divided among the cells when there is no product on the conveyor (tare condition) or the load is at the center mark of the conveyor.

The reader may have noticed that all the examples in this section use only three cells. Most applications can be solved by a three-cell arrangement, unless the designer failed to consult with the load cell supplier early enough in the design phase of the project and ended up with a hopper or tank structure which was driven by the idea of a square section with four legs. Given the difficulty of equalizing or shimming a four-cell system and the effects of temperature gradients on the measurements, eliminating one cell is sometimes a major design improvement.

ONE-CELL SYSTEMS

Many applications can be easily implemented with either a two-cell or a one-cell arrangement, provided the justification criteria are met. This section outlines how these cost-saving systems can be specified and designed.

The simplest one-cell system is the tension cell mounted through rod end bearings and clevises (shown in Load Cells 301). If the cell is properly oriented with the dead end going to the support, the only other major consideration is the elimination or reduction of possible parallel load paths, which are covered in the section on "Parallel Load Paths."

The high-impact platform of *Figure 9* combines the low cost of a one-cell system with the ability to withstand the impact of the rough treatment from handlers of large drums, LPG tanks, etc. The disadvantage of the system is that the center of gravity (*CG*) of the load must be placed on the mark for the calibration of the system to hold true. This can be accomplished by positioning the fences so that the CG of the particular product is located properly when the drum is shoved up against the fences. Two or more products that have different drum diameters can be accommodated by having movable fences with stop pins to position them correctly for each load or by using the multiple-cell capability in the 9840 Smart Indicator by setting up a scale factor for each drum diameter.

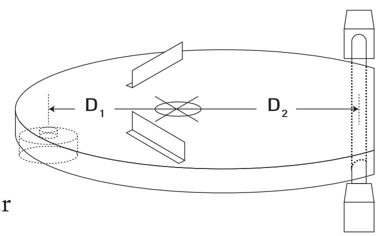


Figure 9. High-Impact One-Cell Platform

The actual load at the (*CG*) of the drum will be factored by the lever arm:

$$L_I = L_T \times \frac{D_2}{D_1 + D_2}$$

Where:

L_I = *Indicated Load*

L_T = *True Load*

D_1 = *Distance from Load CG to Load Cell*

D_2 = *Distance from Load CG to Hinge Line*

This concept has been used successfully for systems handling drums in the range of 180 to 400 pounds. For stubborn impact cases, the load cell can be configured with overload protection or the overload protection can be built into the platform as shown in *Figure 10*. The overload gap should be about 0.05″ to 0.1″, and the spring constant of the flat spring should be such that a load of 110% of the load cell's capacity will cause the platform to hit the stop block, thus shunting the excess load around the load cell.

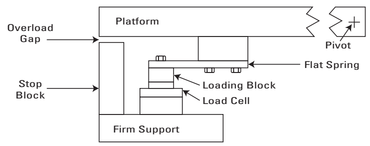


Figure 10. Platform Overload Stop

The concept of the single-cell system works simply because the location of the center of gravity is under control. As long as the force on the primary axis of the load cell bears the same relation to the location of the (*CG*) of the load under all conditions, the scaling will be correct.

In the tension system, the (*CG*) is always directly under the load cell because the rod end bearing forces it to be there.

In the compression system, we can control the location of the (*CG*) if we know the drum diameter by using fences. However, one additional criterion must be met: the (*CG*) must project down to the same location on the platform at any level of filling in the container. For homogeneous materials like liquids in a truly vertical cylindrical container, this will always occur. However, errors can be introduced if the platform is not level, if the container is distorted, or if any other condition causes the (*CG*) to "wander" as the container is filled.

TWO-CELL SYSTEMS

In the two-cell system of *Figure 11*, the weighing rail is supported by the load cells, which are bolted to the main rails. This construction is typical of a warehouse or meat packing plant where the product is moved around by hanging it on a hook that rides on a rail. The rail has one section that is totally supported by two load cells.

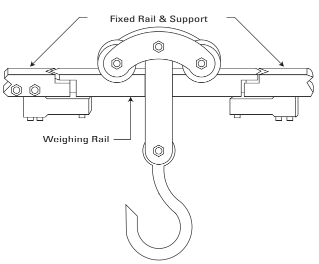


Figure 11. Two-Cell Weighing Rail Section

NOTE:

The gap at each end of the weighing rail is vee-shaped to avoid an impact when the trolley wheel rides across the gap.

As in any system where failure of any of the components could result in damage to equipment or injury to personnel, the weighing section overlaps in such a way that it will be always be supported even if a load cell fails. The general rule on the equipment, other than the load cells, is that the system is proof tested at a load which is five times the operating specification. Naturally, the load cells would be destroyed by such a test, so the system must be designed to retain its integrity even if a load cell fails.

PARALLEL PATHS: PIPES, CONDUIT, AND CHECK RODS

In the optimum design of any system using load cells, all parallel paths (load carrying paths outside the load cells) should be avoided. In cases where parallel paths carry part of the load, any variability in that load will be reflected in an equal error in the load measured by the load cells.

Especially in weighing systems, it is very difficult to avoid parallel paths completely. This is true because most hoppers have some type of power-driven device that requires a connection to the main AC power system or a piping connection for carrying the material into or out of the hopper.

Before the basic design of a weighing tank or hopper is frozen, the support structure and loading/unloading mechanisms should also be evaluated to ensure that none of the parallel paths (pipes, conduit , and check rods) will introduce excessive errors into the weighing system.

For example, *Figure 12* shows a vibrator (a motor with an off-center flywheel) to shake loose the powdery material in the hopper, and a screwfeeder (a long screw inside a pipe which feeds material when turned by the motor/gearbox assembly). The power wiring for both of these devices should be in flexible conduit, if allowed by the local code, and the weight of the conduit should be supported as shown to relieve the hopper from as much of the weight of the conduit as possible.

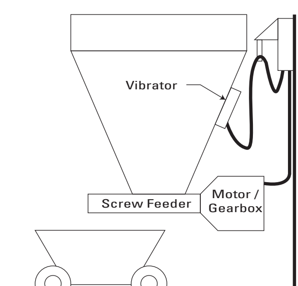


Figure 12. Optimizing Conduit Loading

Figure 13 illustrates three types of uses for compressed air on a hopper. The upper supply injects air through jets in the side of the hopper to fluidize (mix air into a powder or slurry) to make it act like a low-viscosity fluid. The pneumatic valve is a sliding door driven by a pneumatic cylinder. Both of these should be connected to the air supply through flexible hoses because they are parallel paths to the hopper.

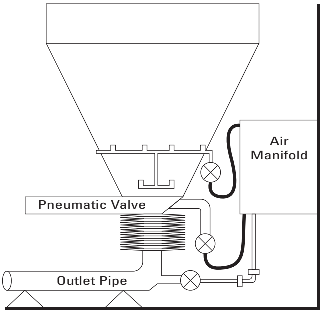


Figure 13. Optimizing Pipe Loading

The outlet pipe is connected to the hopper through a bellows in order to remove the pipe as a parallel path. The connection to inject air into the outlet pipe need not be flexible because is outside of the weighing loop. The electrical wiring to control the solenoid valves is a generally a small enough gauge that it can be neglected.

PARALLELING TWO OR MORE CELLS

UNIVERSAL CELLS

At first glance it would seem that two or more load cells could simply be mounted between parallel plates to create a single assembly with increased capacity, when a larger cell is not available. Unfortunately, this is not the case, and many cells have been destroyed by hidden overloads in this situation.

In addition, unless the assembly is carefully and properly done, errors that are not obvious can be generated, and the output of the assembly could exhibit nonrepeatability, hysteresis, nonlinearity, zero balance instability, and temperature variability, which are higher than would normally be seen in a single cell.

These errors would be the result of the introduction of stresses into the load cells by the process of bolting the load cells into the assembly. A single cell is carefully constructed to be free of internal stresses when at the zero balance condition.

Figure 14 illustrates what happens if the heights of all the hubs in the assembly are not exactly matched when the assembly is torqued tight.

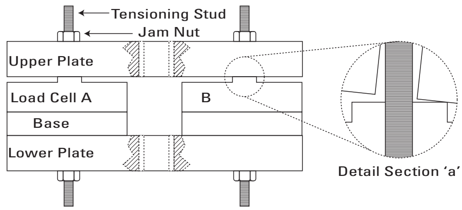


Figure 14. Paralleling LowProfile® Load Cells

Detail/Section (*A-A*) gives an exaggerated picture to demonstrate what happens as the stud in Cell B is tightened to close the gap created by its short hub. Cell B's zero balance shifts in the tension direction because of the tension in the stud to close the gap.

However, that level of tension in the stud is not sufficient to provide a reliable assembly. We must continue to tighten the assembly until the surface of the upper plate and the surface of the load cell hub are flat-to-flat. This results in the introduction of a large moment torque into the load cell. Since the cell is designed to cancel moment inputs, the user may not see a shift in the output due to this moment, but some of the radial beams in the cell could be experiencing a high stress which could destroy the cell in later use.

CAUTION:

The multi-cell assembly will be extremely sensitive to temperature gradients which are introduced by exposing one of the mounting plates to heating without heating the other plate. For example, leaving the assembly in the sun will result in differential expansion between the two plates, which could very likely destroy the load cells.

In the event that it is absolutely necessary to parallel two or more cells, the following steps should be followed explicitly.

1. The plates should be made from 4340 steel plate. Each plate should be at least 1.5 times the nominal thickness of the base which is normally used for the load cells. This is to reduce the amount of bowing of the plates when loads are applied.

2. The bottom surface of the upper plate and the top surface of the lower plate should be ground to a flatness of 0.0005” T.I.R. and a surface finish of 32 µinch.
3. Drill and tap the loading hole in the center of both plates.
4. Drill holes for mounting the cells onto the lower plate. The holes should be on a bolt circle that is centered on the loading hole so that the loads will be distributed equally into all the load cells from the central loading point.
5. Heat treat both plates to a hardness of Rockwell C 33-37.
6. Using Class 3 Socket Drive Set Screws for the tensioning studs, mount the load cells on the lower plate according to the published torque specifications. The studs should be at least long enough to provide square thread engagement beyond the jam nut. Screw the studs into the bases until they hit the stop plug, and then back out one turn. Apply the specified torque to the jam nut.
7. Block up the lower plate assembly (plate plus load cells) on a grinder and indicate the top surface of the plate. Shim the plate on the table of the grinder until the top surface of the plate measures less than 0.001” T.I.R. and check the plate assembly to make it is clamped securely.
8. Indicate the top surface of each load cell hub to find the lowest hub. Taking very slow feeds and light cuts, grind the top surface of the load cells’ hubs until they are all ground down to the match the lowest hub. Continue to grind until the whole hub surface of the lowest hub has been ground. Allow the cells to cool and reach temperature equilibrium for at least 4 hours. Take one more slow pass to ensure that all the cells’ hubs are in one plane within 0.0002” T.I.R., referenced to the surface of the grinder’s table.
9. Place the upper plate in position and install the studs and jam nuts. If necessary, hold the studs from turning with an Allen wrench. Torque the jam nuts to a barely snug condition, 5 to 10 lb-ft of torque. Do not attempt to apply jamming torque to the studs or the jam nuts at this time.

10. Mount the assembly in a load frame with a capacity of about twice the rated capacity of one of the load cells in the assembly, as shown in *Figure 15*.

11. Using the output of Cell A as a measure, apply a tension of 120% to 130% of the rated capacity of Cell A. The jamming on the tension studs will be relieved by this force, and the jam nuts on both studs should then be tightened to 5-10 lb-ft of torque. Do not torque the jam nuts any tighter. When the tension is released, the studs' threads will be firmly set, and the jam nuts will be set properly.

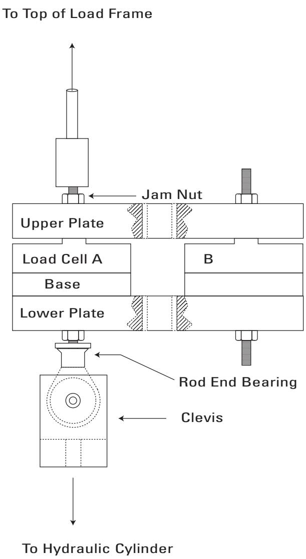


Figure 15. Final Tensioning of Multiple-Cell Assembly

NOTE:

The actual force required to achieve the proper tension on the load cell during the tensioning operation will be higher than indicated on the load cell output, because of the deflection of the upper and lower plates required to bring the load cell beyond full capacity. The plates are restrained by the parallel paths of the other load cells in the assembly.

12. Repeat Step 11 for the other load cells in the assembly. Use the output of the load cell being tensioned as the indication of the force being applied to it.

13. When all the cells have been tensioned, measure and record the zero balance of each load cell.

14. Connect all the cells to the signal conditioner, cables, and junction box with which they were calibrated at the factory.

15. Mount the whole assembly on the load frame and apply a conditioning load of 100% of the theoretical capacity of the assembly through the loading holes. Repeat the loading two more times. Measure and record the zero balance of each load cell individually.

16. Apply the conditioning load one more time and record the zero balances again.
17. Compare the zero balances for each load cell and verify that the last conditioning load resulted in only a minor shift in zero balance. If the shift was greater than 0.05% RO, the conditioning loads should be repeated.
18. The assembly is now ready for final calibration. The original factory calibration will be useful for comparison purposes, but it is not valid for the final assembly because the outputs of the load cells will be affected by the side loads and moment loads applied to the cells due to bowing of the upper and lower plates.

CAUTION:

In a multilevel tension assembly, the rated capacity should be limited to 80% of the calculated theoretical capacity because of the unavoidable and unmeasurable residual stresses which are induced in the individual load cells by their being restrained between two stiff plates.

COMPRESSION CELLS

In a multi-cell compression system, the top plate is a ground and hardened steel plate, with a surface finish of 32 μinch. It is merely resting on the load buttons of the cells. The paralleling of compression cells can be very straightforward, if these simple rules are followed:

1. For two cells, the upper plate must be supported from tipping, since it is not bolted to the top side of the compression cells. It is simply resting on their load buttons.
2. Three cells is the optimum number because the three load buttons will provide a stable support for the upper plate.
3. Four or more cells are quite difficult to assemble, because the low cell must be shimmed until it makes all the load buttons lie in one plane within no worse than 0.0005”.
4. The requirements for the lower plate are the same as for the universal cells, as given above.

interface
FORCE MEASUREMENT SOLUTIONS™

Interface® is the trusted The World Leader in Force Measurement Solutions®. We lead by designing, manufacturing, and guaranteeing the highest performance load cells, torque transducers, multi-axis sensors, and related instrumentation available. Our world-class engineers provide solutions to the aerospace, automotive, energy, medical, and test and measurement industries from grams to millions of pounds, in hundreds of configurations. We are the preeminent supplier to Fortune 100 companies worldwide, including; Boeing, Airbus, NASA, Ford, GM, Johnson & Johnson, NIST, and thousands of measurement labs. Our in-house calibration labs support a variety test standards: ASTM E74, ISO-376, MIL-STD, EN10002-3, ISO-17025, and others.

You can find more technical information about load cells and Interface®'s product offering at www.*interfaceforce.com*, or by calling one of our expert Applications Engineers at *480.948.5555*.

NOTES

NOTES