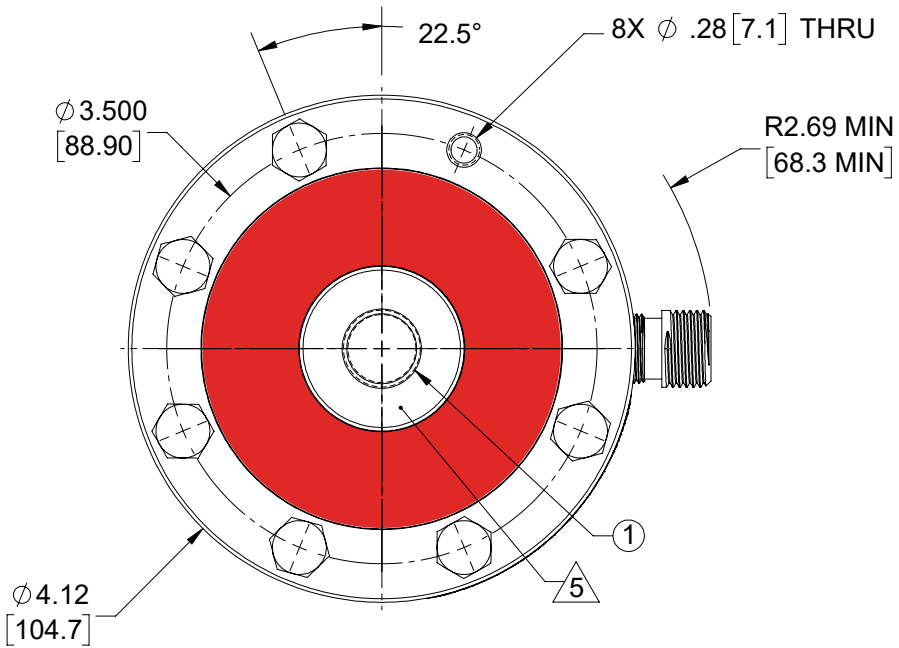


# interface

FORCE MEASUREMENT SOLUTIONS.

## LOAD CELLS 501 GUIDE

MATERIALS & PROCESS CONTROL TESTING



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The Interface Load Cell 501 Guide examines materials and process control testing. Compiled by force measurement engineers and specialists, this advanced resource provides in-depth knowledge and practical strategies relating to material behavior under various loading conditions.

This comprehensive handbook goes beyond basic load cell applications, immersing you in the world of material characterization. With its illuminating explanations, illustrative figures, and insightful scientific principles, the guide equips you with the tools to leverage load cell technology, enhancing your understanding of materials and processes in a practical and tangible way.

Starting with the fundamental relationship between force and deflection, we analyze how materials respond to applied loads, a cornerstone for optimizing material selection and process control.

We take a detailed approach to the concept of shear force versus compaction, ensuring you have the expertise to distinguish between these critical forces and their impact on material behavior. The guide also explains the measurement of peel force, a crucial aspect of evaluating the strength of adhesive bonds between dissimilar materials.

Use this guide to learn about conducting safe and reliable load testing while safeguarding both the load cell and the sample under test. It also explains how to find an object's center of gravity (CoG), which is crucial for many test applications.

Learn the complexities of fatigue testing, a technique for assessing a material's ability to withstand repeated loading cycles. By understanding fatigue testing standards and capacities, you can discover how to design and execute robust fatigue tests to predict material performance under long-term use conditions.

The guide further examines principles for determining a material's fatigue resistance and making informed decisions about its suitability for specific applications. It tackles the crucial topic of using non-fatigue-rated cells in fatigue applications. We continue by highlighting potential risks and considerations in such scenarios, enabling you to make informed decisions based on specific testing requirements.

We continue in the guide with an exploration into fatigue capacity with an added fixed load. This section equips you with the knowledge to analyze how a constant load can influence a material's fatigue resistance, providing valuable insights for real-world applications.

The final in our sequenced series, the Interface Load Cell 501 Guide, is your trusted companion in materials and process control testing.

Your Interface Team

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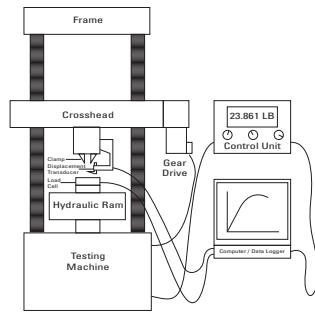
# MATERIALS & PROCESS CONTROL TESTING

The testing of materials and complex assemblies is such a vast field that it is impossible to cover all aspects of it completely in this manual. In this section, we will provide an overview of the different types of material tests and other specialized tests using force as a variable, with some examples of the most common applications.

## FORCE VERSUS DEFLECTION

In the determination of the force versus deflection characteristics of a raw material, a fabricated part, or an assembly, it is usually necessary to control the position and orientation of the Unit Under Test (*UUT*), to control the direction and magnitude of the applied force, to measure one or more displacements, and to measure any other parameter which may vary with the force or displacement. For these reasons, a large market has developed over the years for sophisticated testing machines and their associated fixtures, transducers, and signal conditioning and recording equipment.

In the typical materials testing machine shown in *Figure 1*, where the clamp is shown, various other fixtures can be attached to hold, or even rotate, the (*UUT*) during the test. Other transducers can be mounted to measure torque, angle, pressure, or any parameter for which the customer is willing to pay. It is not unusual to test for torque and linear force concurrently, and the Interface LowProfile® cells are eminently suited for this because of their high rejection of extraneous loads.



*Figure 1. Typical Materials Testing Machine Setup*

With the hydraulic ram at a solid stop, the gear drive can be servo-controlled to advance the displacement at a very accurately controlled rate, to determine the time dependency of a material's characteristics. Or, with the gear drive locked, the hydraulic ram can apply a precise force profile, as controlled by the load cell.

In general, any modern test machine is programmed and controlled by its own internal microprocessor, with facilities for accepting large volumes of

control information and transmitting high rates of measured data either to a local data logger or to a network server for further processing.

## SHEAR FORCE VERSUS COMPACTION

In the determination of shear strength versus compaction of soils or construction materials, the object is to determine the shear strength as the material is used at different depths underground or at different levels in the construction of a high-rise building. Usually, a special test block is designed to test a particular type of material in conformance with a specification.

The test block is designed with a rectangular hole going through it, into which the tested material is inserted.

To set up for the test, the shear block is put into position in the test block so that the hole in the shear block lines up with the rectangular test hole. The material under test is then packed into the hole, up through the hole in the shear block, and almost to the top of the test block.

Finally, the compaction piston is inserted, and the material is evenly pressed down to fill the hole and remove air pockets and voids.

The actual test is performed in a test frame much like a materials test machine, except that it has an additional capability to pull out the shear block while measuring the shear force and shear deflection. To perform the test, the compaction force is first applied on the top of the compaction piston by a compression load cell, and then the tension shear force is applied to the shear block by another load cell. The test is repeated for a range of compaction forces, and the output from the test is a table of figures or a graph of shear force versus compaction force.

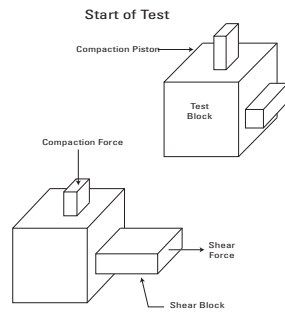


Figure 2. Soil Shear vs Compaction

## PEEL FORCE

A common test for adhesives, adhesive-coated tapes, and paints is the peel test. The test parameters are usually detailed in a government or industry specification, and the rate of pull is often closely controlled. Adhesive-backed tapes are tested this way. Also, paint adhesion is tested by applying the paint according to instructions, applying a specified adhesive-backed tape to the painted surface, and then pulling the tape off in a specified way.

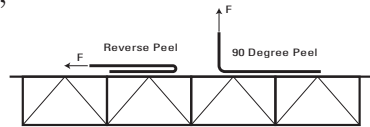


Figure 3. Adhesive and Paint Peel Test

## ADHESIVE OR BONDING SHEAR FORCE

There are literally thousands of adhesives and bonding agents that are used to assemble parts into assemblies. In addition to their bonding characteristics, they may be required to have a certain elasticity, resistance to chemicals, electrical conductivity, temperature coefficient, or other controlled parameter.

In addition to the general-purpose shear test machines on the market, many testers are designed and constructed in-house to perform specific tests on unique assemblies.

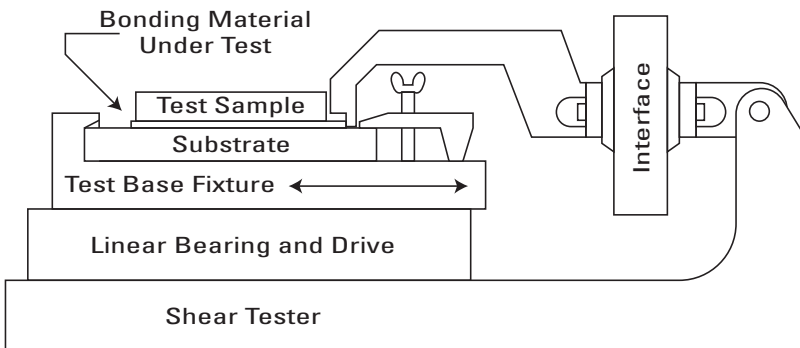


Figure 4. Adhesive Bond Shear Tester.

The design of a shear tester is relatively straightforward, as long as the following conditions are met:

1. The line of action of the primary axis of the load cell should be aligned with the contact point on the test sample, to minimize moment loads on the load cell.
2. The linear bearing motion should be carefully adjusted to run exactly parallel with the primary axis of the load cell, to avoid a side load into the load cell.
3. The load cell's capacity should be at least twice the expected maximum load to be applied during a test cycle, to provide enough extra capacity to protect the cell when a sudden failure of the test sample impacts the load cell.
4. The linear drive should have a wide range of controlled speeds and a high resolution displacement measuring capability, including an automatic adjustable stop with fast braking to protect the load cell from damage. A stepper motor drive with precision high-ratio reduction gear is the usual system of choice.

## SAFETY: PROOF TESTING AND THE COMPRESSION CAGE

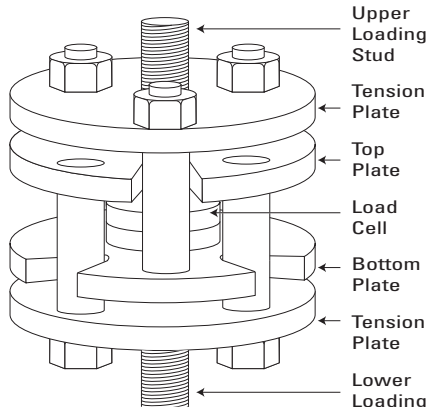


Figure 5. Compression Gage



Many industry and government specifications require testing the components of a system at many times the rated or nameplate loading, where the failure of the component could result in costly damage to equipment or injury to personnel.

The most sensitive product liability area for load cell manufacturers is the use of a load cell in tension on a crane which lifts loads where it is possible that a person could be under the load, even by mistake. Proof testing in this case usually requires that the equipment be proof tested at five times its rating. Obviously a tension load cell could never survive such a test. Interface® never recommends using a tension load cell in this type of application.

The most straightforward solution, where it is necessary to measure the load in a tension cable subject to safety considerations is to enclose the load cell in a compression cage, which converts tension into compression. The compression cell is trapped between the two plates. Thus, the load cell's only overload failure mode is in compression, which allows a motion of only 0.001" to 0.010" before the load cell becomes solid. Even if the load cell is totally destroyed, the compression cage cannot drop the load unless it fails itself. Therefore, the cage can be proof-tested with a dummy load cell, or an overload protected cell, and the risk of injury to personnel is avoided.

## FINDING CENTER OF GRAVITY

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One of the critical tests on missile assemblies is the determination of the center of gravity, because variations in the weight distribution in a missile can have a disastrous effect on its flight stability.

The test stand shown in *Figure 6* typifies the elements which need to be addressed to optimize the test.

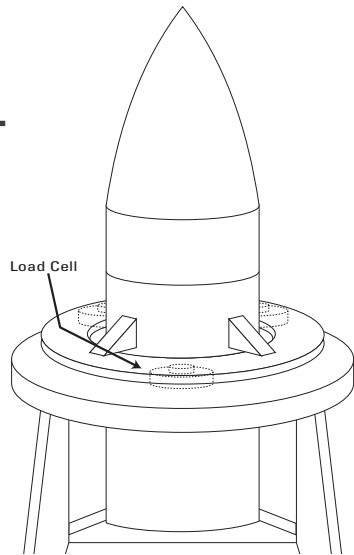


Figure 6. Center of Gravity Test Stand

1. Three cells instead of four will simplify the design, construction, and use of the test stand immeasurably.
2. The mounting ring should be as close as possible to the level of the center of gravity of the (*UUT*). The farther the reference hard pads are displaced from the center of gravity, the more the test stand will be subject to errors due to leveling, misalignments, and temperature effects.
3. A calibration dummy load should be constructed which has the same weight as the (*UUT*), and whose center of gravity is at exactly the required location. This will dramatically decrease errors due to nonlinearity of the load cells.
4. The test stand should be leveled each time it is used, and the cells should be carefully exercised with the dummy load and checked for calibration.

The designer who promotes a three-cell system may meet with some opposition from engineers whose minds are used to working in an orthogonal (right angled) reference system. However, the mechanical headaches associated with the shimming of a four-cell system and readjusting it when the temperature varies justify the extra effort to solve the equations for a triangular system.

For example, if the center of gravity (*CG*) is supposed to be at the exact center of the triangular pattern of the load cells, the diagram in *Figure 7* shows the load cells at A, B, and C all measuring exactly the same loads ( $\alpha$ ,  $\beta$ , &  $\gamma$ ). When those load vectors are plotted as distances from their respective opposite sides (which are the fulcrums against which the vectors operate), we find that they coincide at the (*CG*), at the exact centroid of the triangular load cell pattern.

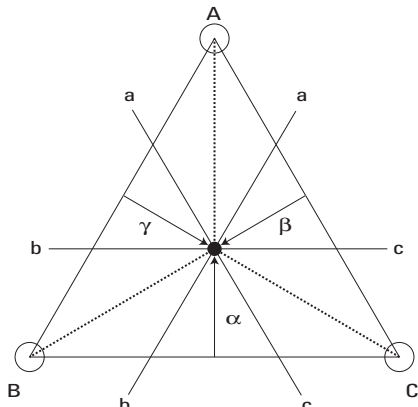
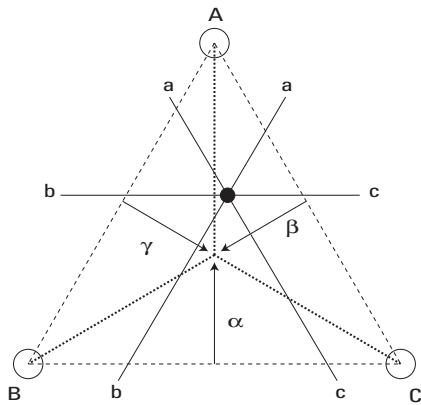


Figure 7. *CG Exactly on Centroid of Cells*

This means that the ( $CG$ ) is exactly where it should be, and it also gives us fair assurance that the system has been properly calibrated.

However, if the ( $CG$ ) is mislocated in the missile, as in *Figure 8*, the vectors will define a different set of distances from their respective fulcrums. When we measure the vector  $\alpha$  from the baseline ( $BC$ ), we construct line  $bc$  parallel to the baseline ( $BC$ ). In the same manner, we construct line  $ac$  at distance from baseline ( $AC$ ). The intersection of lines ( $ac$ ) and ( $bc$ ) defines the ( $CG$ ) point.



*Figure 8. CG Mislocated*

The question then arises, “How did we find the ( $CG$ ) without using line ( $ab$ )?” The answer is, “Any two of the lines could define the ( $CG$ ), because the data from all three cells was used to define the two lines, and the intersection of two lines defines a point.”

The position of the third line is a redundant check, and is a nice way of checking the accuracy of the measurement. If the third line (whichever one we choose) does not go through the same point as the intersection of the first two lines, we need to check our test system and find the error, because all three lines should agree on the location of the ( $CG$ ). In *Figure 91*, the ( $CG$ ) is mislocated, but all three lines agree on the intersection point. Thus, the test is good, but the ( $CG$ ) is mislocated in the missile.

## FATIGUE TESTING

The use of load cells and a data logging system are a necessity in the majority of situations in which materials, parts, or assemblies are fatigue tested to destruction. This is true because an accurate record of the forces at every moment of the tests is the only way that an engineer can analyze the stresses which occurred in the moments just prior to the ultimate failure. No one can accurately predict exactly when the failure will occur, nor which part of an assembly will be the weakest link that eventually will fail.

When designing a test protocol, serious thought should be given to the possibility that some of the parameters of the test will need to be changed as the result of information learned in the early test cycles. It may be that the test frequencies, force levels, location or angle of force application, or phasing of test waves will need to be changed. It is therefore prudent to start out with equipment that can accommodate an increase, a decrease, or other change without a major redesign of fixtures or a major expenditure to convert or replace expensive test equipment.

## **FATIGUE CAPACITY**

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“Fatigue Rated” is an exact Interface® specification which defines a special class of load cell design and construction.

- Design stress levels in the flexures are about one-half as high as in a standard LowProfile® load cell.
- Internal high-stress points, such as sharp corners and edges, are specially polished to avoid crack propagation.
- Extraneous load sensitivity is specified and adjusted to a lower level than in a standard LowProfile® load cell.
- All fatigue rated Interface® cells have a specified service life of 100 million fully reversed, full capacity loading cycles.

Not all manufacturers adhere strictly to the stringent discipline that is necessary to produce true fatigue-rated load cells on a consistent basis. By contrast, the history of Interface® LowProfile® cells shows a zero return rate due to fatigue failure, for fatigue-rated cells used within ratings.

## **USE OF NON-FATIGUED-RATED CELLS IN FATIGUE APPLICATIONS**

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Although Interface® does not recommend it, there are times when circumstances force a user to apply a large number of test cycles on a non-fatigue-rated cell. The following guidelines may assist the user in deciding how long to carry on such a test before installing the properly sized fatigue-rated cell.

1. All Interface® non-fatigue-rated load cells can be considered to have a useful life of at least one million cycles of single-mode loading (loading

in only one direction), at full nameplate rating. Therefore, if used in single mode at 50% of rating, it is likely that a cell would survive at least ten million cycles.

2. If used at 50% of the cell's rating, the material used in steel and stainless steel Interface® cells would be stressed below the endurance limit, the level at which the steel itself would resist failure indefinitely.

**CAUTION:**

*If this were the only failure mode, any Interface® steel or stainless steel cell could be used as a fatigue cell, if operated below 50% of its rated capacity. However, other minor failure modes would take over, because the load cell would be missing the “hand crafted” steps of the manufacturing process.*

3. Aluminum alloy load cell material does not exhibit an endurance limit, the horizontal flattening of its S-N Curve, the operating curve of stress versus number of cycles to failure. Therefore, while use at 50% of rating will substantially increase the number of cycles it will withstand, no exact number of cycles can be predicted.
4. One failure mode which has not been tested on non-fatigue models is the number of cycles to failure of the connecting cable versus the extension the cable is subjected to on each cycle. Users should take steps to support the cable in a way which reduces the stresses for larger extensions.
5. Since the application of dynamic forces during a test involves bi-directional motion, there is a larger risk of contact resonance due to clearances in the driving mechanism. (See the section on Contact Resonance.) Any contact resonance generates non-sinusoidal forces having a high frequency content which has a greater effect on the cycle count on the load cell and also generates peak loads which are greater than the measured average.

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## **FATIGUE CAPACITY WITH AN ADDED FIXED LOAD**

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Many test protocols require a fixed load plus a dynamic load to be applied to a test sample simultaneously. An Interface® fatigue-rated load cell is well suited to this type of application. However, there are limitations which should be applied to the loadings, to insure that the cell will be

operating in its linear range and avoid overloading the load cell or reducing its fatigue life.

The Goodman Curve shown in *Figure 9* is a useful nomograph (visual calculating graph) for easily figuring combined loading limits for fatigue-rated cells. Notice that the dynamic loading limit by itself is 100% of the fatigue rating, and the static loading limit by itself is 200% the fatigue rating. In between these two end points, the limit is the diagonal straight line which connects the end points.

**CAUTION:**

*The Goodman Curve applies only to fatigue-rated cells. Using it to calculate combined loadings on a standard load cell could result in damage to the cell.*

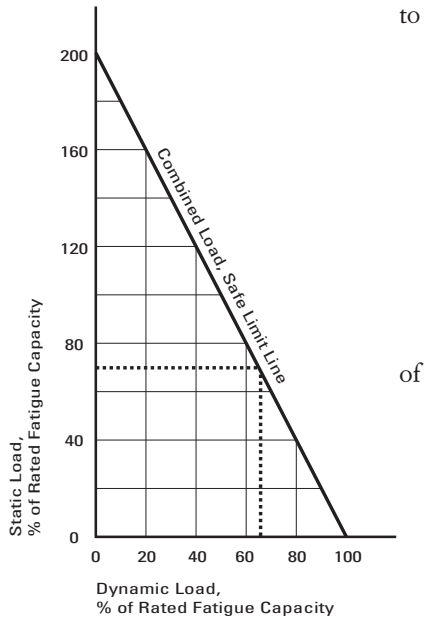


Figure 9. Nomograph for Safe Limits of Combined Static and Dynamic Loading

In the example shown on the graph the dashed line indicates a situation where we want to apply a fixed load of 70%, and we want to know how much dynamic load we can apply simultaneously. By taking a straight horizontal line at the “70% Static Load” level across to the limit line and then projecting downward from that intersection, we find that the intersection on the dynamic scale at “65% of Rated Fatigue Capacity.” This means that on a 1000 lbf rated fatigue cell we could apply a fixed load of 700 lbf combined with a dynamic load of 650 lbf peak in both modes.

Checking the graph, note that if we needed to apply a fixed load of 160%, we could still apply a dynamic load of 20% for a total load which varies between 140% (lower peak) and 180% (upper peak). This would mean that the cell would be operating outside of the limit of the normal factory calibration on fatigue cells of 100%. If the utmost accuracy is desired, it might be advisable to have a static calibration performed on the cell up to 200%, which can be done on a fatigue-rated cell by special order.

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**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](http://www.interfaceforce.com), or by calling one of our expert Applications Engineers at 480.948.5555.







