MATERIALS AND 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 give 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 *UUT* (Unit Under Test), 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.

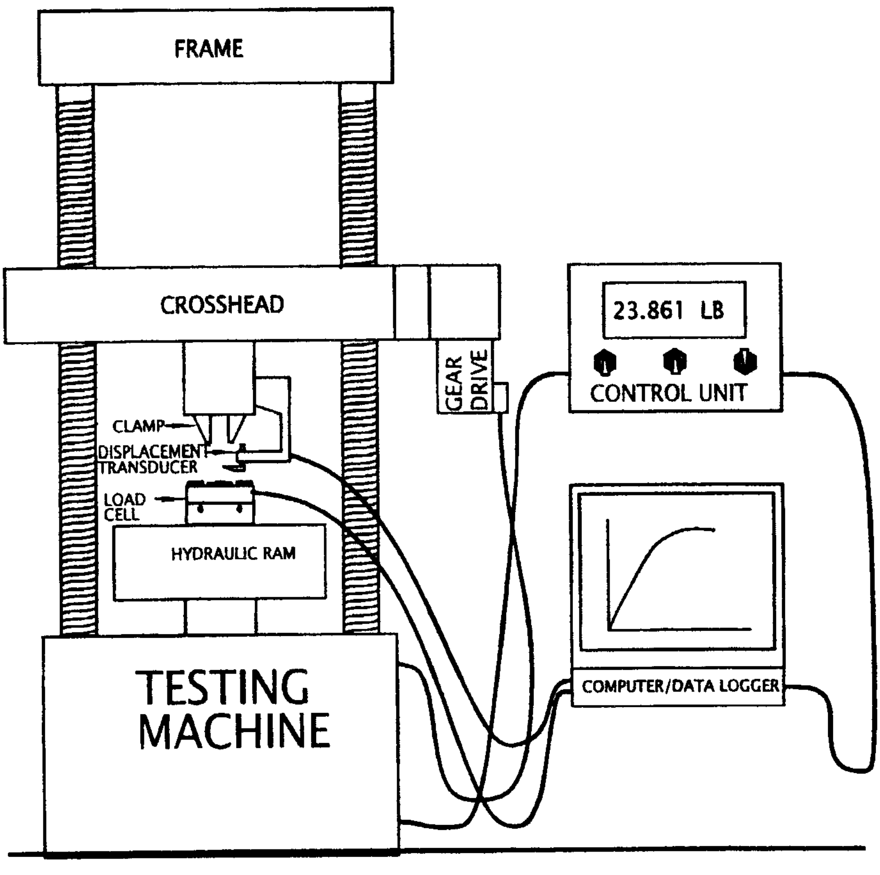

Figure 42. Typical Materials Testing Machine Setup

In the typical materials testing machine shown in Figure 42, 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 the customer is willing to pay for. It is not unusual to test for torque and linear force concurrently, and the Interface Low Profile cells are eminently suited for this because of their high rejection of extraneous loads.

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 datalogger 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.

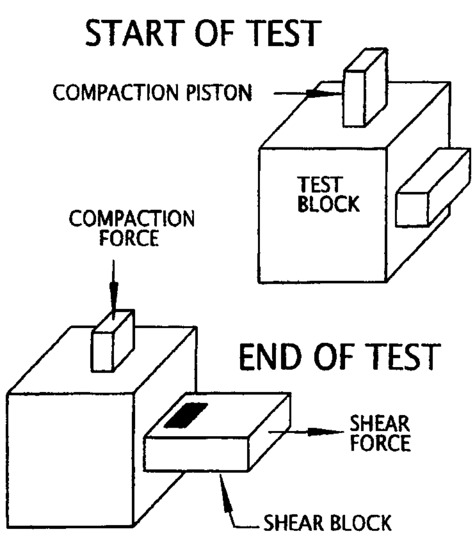

Figure 43. Soil Shear Versus Compaction

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.

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 most 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.

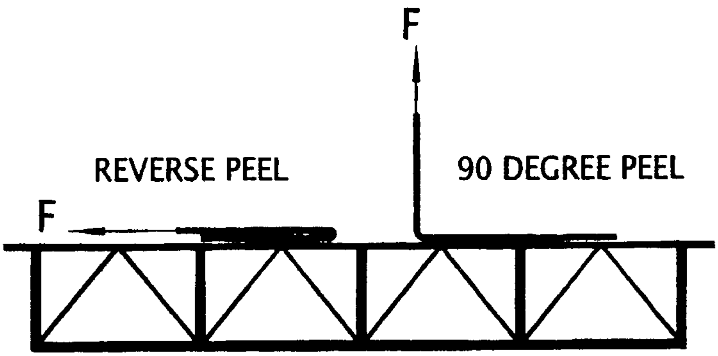

Figure 44. Adhesive and Paint Peel Test

Adhesive or Bonding Shear Force

There are literally thousands of adhesives and bonding agents which 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.

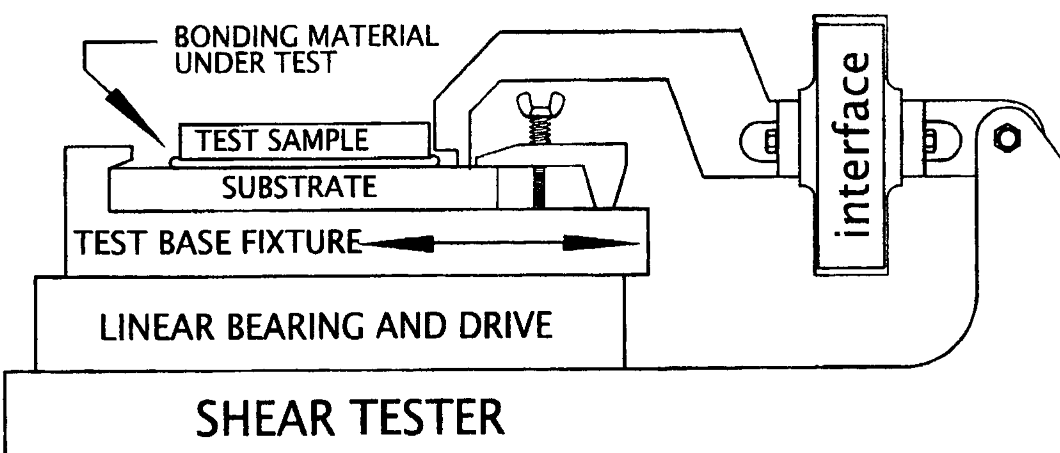

Figure 45. Adhesive Bond Shear Tester

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

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

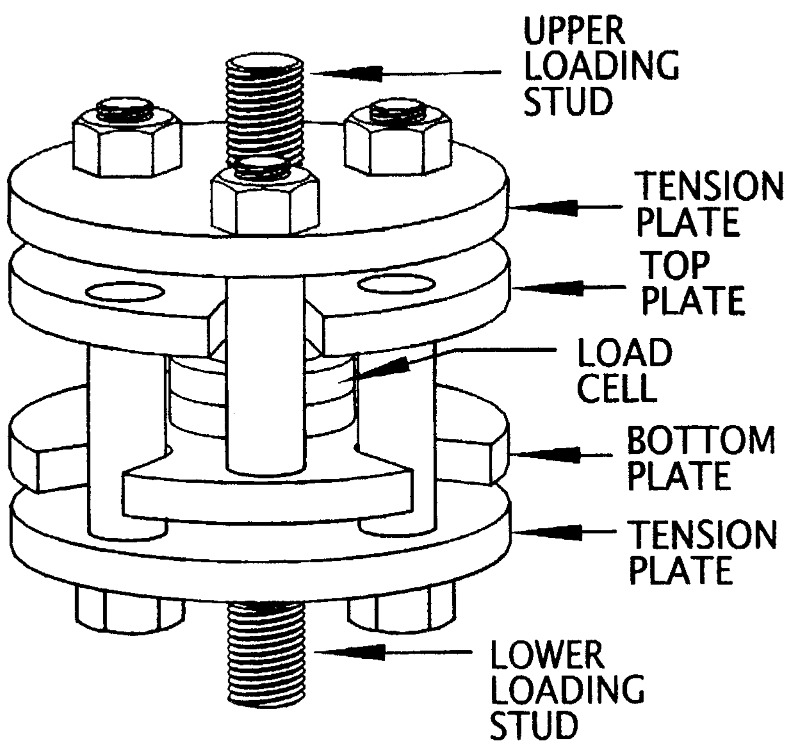

Figure 46. Compression Cage

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

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 disasterous effect on its flight stability.

The test stand shown in Figure 47 typifies the elements which need to be addressed to optimize the test.

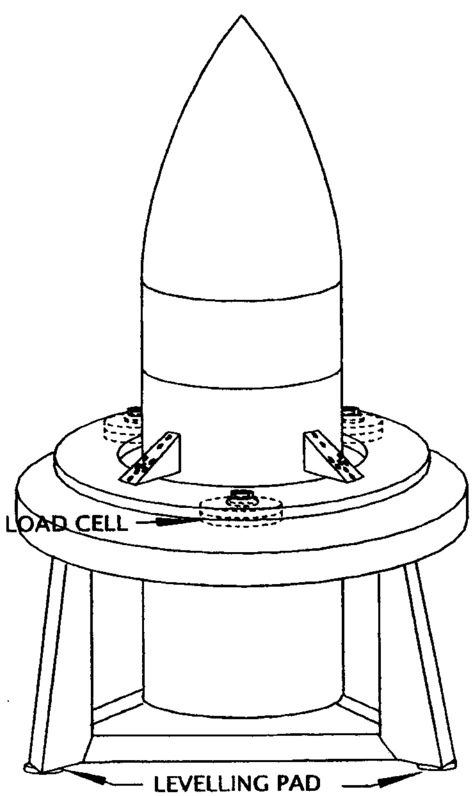

Figure 47. Center of Gravity Test Stand

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 levelling, 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 non-linearity of the load cells.
4. The test stand should be levelled 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 are worth the extra effort to solve the equations for a triangular system.

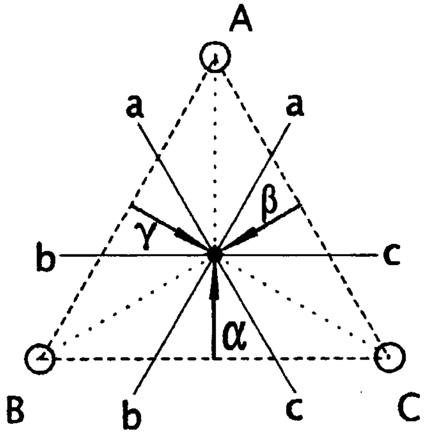

Figure 48. CG Exactly on Centroid of Cells

For example, if the CG (center of gravity) is supposed to be at the exact center of the triangular pattern of the load cells, the diagram in Figure 48 shows the load cells at A, B, and C all measuring exactly the same loads α, β, and γ. 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.

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 49, the vectors will define a different set of distances from their respective fulcrums. When we measure the vector α from the baseline BC, we construct line *bc* parallel to the baseline BC. In the same manner, we construct line *ac* at distance β from baseline AC. The intersection of lines *ac* and *bc* defines the CG point.

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."

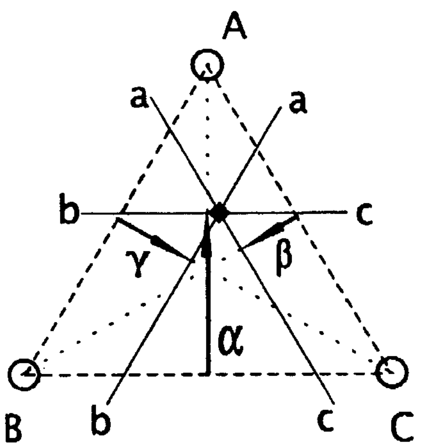

Figure 49. CG Mislocated

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 49, 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 where 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 which eventually fails.

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 which can accomodate an increase, a decrease, or other change without a major redesign of fixtures or a major expenditure to convert or replace high cost test equipment.

Fatigue Capacity

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

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

Not all manufacturers adhere strictly to the stringent discipline necessary to produce true fatigue rated load cells on a consistent basis. By contrast, the history of Interface Low Profile 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

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 excursion 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 excursions.
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, page 14.) 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.

Fatigue Capacity With an Added Fixed Load

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 to avoid overloading the load cell or reducing its fatigue life.

The Goodman Curve shown in Figure 50 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% of 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

In the example shown on the graph, the dashed line indicates a 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.

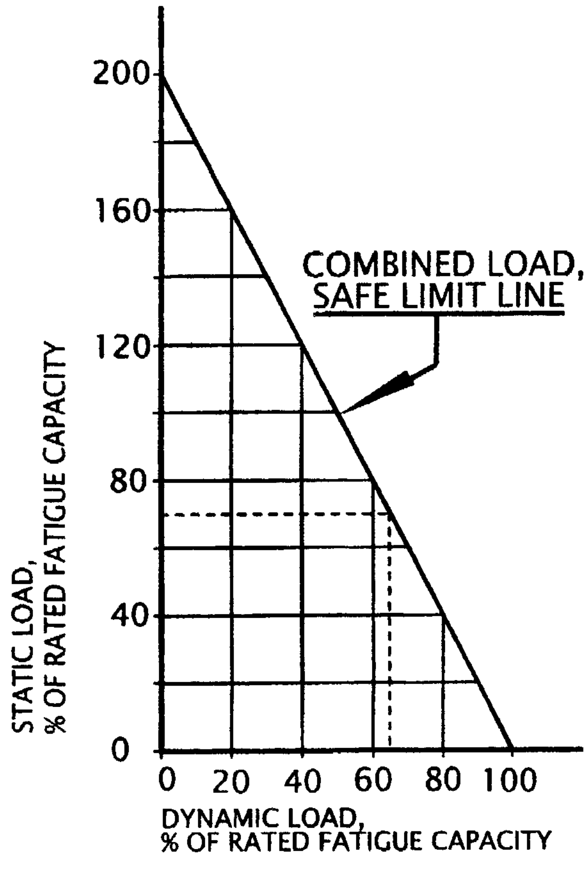

Figure 50. Nomograph for Safe Limits of Combined Static and Dynamic Loading

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 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 done on the cell up to 200%, which can be done on a fatigue-rated cell by special order.