LOAD CELLS AND STRAIN SENSORS FOR PRESSWORKING APPLICATIONS

Accurate high capacity load cells are needed for press tonnage monitor calibration. They are also useful for some types of press testing. Calibration load cells have a metal structure to which strain sensors or strain gages are attached. The metal structure is compressed when subjected to load. The attached gages provide an electrical output that is a linear function of applied load if the *proportional limit* of the metal structure is not exceeded.

Figure 1. A 1,000-ton (8896 kn.) press calibration load cell having a total of 32 strain gages installed on the inside and outside of a hollow steel cylinder. *Smith & Associates*
Usually, hardened tool steel is employed in order to increase the capacity of the supporting structure. Heat treatment increases the proportional limit of the steel, and thus extends the capacity of the cell. Strain gage based load cells are available in capacities ranging from a few grams through 1,500 tons (13,344 kn.) or more.

Figure 1 illustrates a 1,000-ton (8896 kn.) press calibration load cell having 32 strain gages installed on the inside and outside of a hollow steel cylinder. Both the inside and outside of the cell is gaged in order to increase accuracy, when placed on support surfaces that are not perfectly flat.

Historically, the design of this type of load cell is similar to those developed by Baldwin Lima Hamilton Electronics (BLH) for steel rolling mill slab thickness control. A comparable design was produced with a capacity of 1,500 tons (13,344 kn.) by BLH in 1954.  

### 250 Ton Load Calibration Load Cell

![Image of 250 Ton Load Cell](image)

**Figure 2.** A 250-ton (2,224 kN) load cell designed for press testing and tonnage monitor calibrations. *Toledo Transducers, Inc.*

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Figure 2 shows a 250-ton (2,224 kN) load cell. This type of cell is an old proven design. In addition to press calibration, cells of this type may be used as a substitute for force proving rings to calibrate testing machines. A carefully constructed load cell of this type can be constructed with an accuracy and linearity of 0.007%, or better.

A 100-Ton Load Cell with the Cover Removed

Figure 3. The hourglass structure of a load cell similar to the one shown in Figure 2 with the protective steel sleeve removed. This load cell has a capacity of 100 tons (890 kN). Toledo Transducers, Inc.

Basic Compression Load Cell Construction
The load cell body is made of hardened tool steel that is accurately machined and finished to close dimensional tolerances. Careful machining and heat treating helps assure good uniformity for cell-to-cell and long-term stability. As shown in Figure 3, the strain gages are cemented to the steel load cell body and are protected with a waterproof encapsulating compound.

The load cell body has a straw or light brown appearance due to the normal surface oxidation of steel that occurs when curing the special high stability cement used to affix the strain gages to the load cell body. The cement is cured at approximately 350° F (177° C) in an oven having precise temperature control.
Advantages of Hourglass Shaped Compression Load Cells
The hourglass shaped load cell design shown in Figure 3 is an old proven design. In many cells of this type, eight strain gages are used. The gages are carefully spaced in pairs at locations 90° apart around the center of the hourglass shaped structure. This arrangement will give accurate readings although the cell may not be uniformly loaded.

A Unique Load Cell with a Built in Readout
A load cell such as the unit illustrated in Figure 2 is designed to work in conjunction with an external readout device. Press calibration work involves running heavy-duty strain gage wiring around or through the press to the external readout device.

Figure 5 illustrates the 100 tons (890 kN) load cell structure in the testing machine shown in Figure 4.
Autocell™ Self Contained Load Cell with Readout

Figure 5. An Autocell™ brand 250 tons (890 kN) loadcell having a built in LED readout powered by a 9-volt battery. Toledo Transducers, Inc.

In Die Force Monitoring

Precision in-die force monitoring may be accomplished by means of load cells, which are placed under die members such as punches, die buttons, staking anvils or coining stations. Either a strain gage based or piezoelectric load cell may be employed. The output is an electrical signal that is directly proportional to force.

Load cells can be built directly into dies to measure critical operations. For example, the depth of the score in beverage can tops is very critical. The scribe must fracture easily when opened; yet not leak in shipment and storage. The die station used to form the score is often mounted on especially designed load cells. Any slight change in the operation is detected. In this way, on line process control avoids producing defective products.
Custom Built in Die Load Cell

Figure 6. A custom-built load cell for in die force monitoring. Note the strain gages and wire termination pads cemented to the steel body. Toledo Transducers, Inc.

Example of Custom Made Load Cell
Figure 6 illustrates a custom-built load cell for in die force monitoring. A pair of strain gages and special wire termination pads is cemented onto the steel body. The strain gages and wiring are protected with a special protective compound.

Obtaining Greater in Die Load Cell Sensitivity
To obtain greater sensitivity in the strain gage based types; the metal load cell structure is sometimes made of aluminum alloy rather than steel. The increase in sensitivity is inversely proportional to the difference in the modulus of elasticity, typically a factor of approximately three. Aluminum load cells are typically used for applications where loads ranging from a few grams to several kilograms are to be measured.

Figure 7 illustrates another view of the special in die load cell shown in Figure 6. The hole through the center reduces the cross sectional area of the steel structure, which will increase the sensitivity of the cell.

Another purpose of a hole in the center of an in die load cell may be for the discharge of a part or slug. Placing a hollow load cell under a critical cutting station is an effective way to detect dulling of the tooling and/or stock condition changes.
Hollow Custom Load Cell Structure

Figure 7. Hollow custom in die load cell structure. The hollow cell may be used to increase load cell sensitivity or the passage of parts or slugs. *Toledo Transducers, Inc.*

Cleaning Soldering Flux from Custom Load Cell

Figure 8. A swab and solvent are used to clean the soldering flux from a custom in die load cell prior to applying a protective coating. *Toledo Transducers, Inc.*
Piezoelectric Load Cells

A second type of precision load cell often used for in-die force monitoring applications makes use of a piezoelectric material, such as quartz, that is directly compressed by the pressworking operation. The output is a voltage proportional to load is developed across the faces of the sensor.

A broad product line of piezoelectric load cells is produced by PCB Piezotronics of Depew, New York. Many load cells in their product line feature internal charge amplifiers, which provides a large output capable of driving a variety of data acquisition equipment.

Non-Calibrated Bore Hole Probes
Force readings can be obtained by means of borehole strain probes. These are inserted into a drilled hole in a die shoe or tooling retainer and fastened by means of cement, a drawbar or screw actuated wedge. These are available in both strain gage and piezoelectric types. The output is not easily calibrated and hence of little use for engineering calculations of tooling operating parameters. They are useful where alerting the operator to a change in force is sufficient.

Figure 9. A false waveform resulting from connecting a piezoelectric die bore hole probe directly to low impedance instrumentation input. Smith & Associates
Disadvantages of Piezoelectric Bore Hole Probes
A disadvantage of piezoelectric borehole probes is the need to have a charge amplifier or interface device having extremely high input impedance. This is needed to convert the high impedance voltage output to low impedance that can be interfaced with data acquisition devices.

Figure 9 illustrates a piezoelectric borehole probe installed in a die shoe. Because the output of the probe is an electrical charge or voltage, a false waveform is indicated on an oscilloscope connected to the probe. What is occurring is the charge drains away so quickly that there is essentially zero signals at the bottom of the press stroke. Therefore, an opposite (negative) pulse is seen as the strain on the probe is released on the press upstroke.

Figure 10. A true waveform of a forming or coining load requires an oscilloscope or other data acquisition device with very high input impedance. Smith & Associates

Figure 10 shows a normal waveform of a forming or coining load. Here, the piezoelectric probe is connected to an instrument having very high input impedance.
Strain Gage Instrumented Bottoming or “Kiss” Blocks

Figure 12. Strain gaged setup or stop blocks used for critical pressworking applications. These “kiss” blocks are carefully calibrated and have NIST traceability. Toledo Transducers, Inc.

Using Special Load Cells as Stop or “Kiss” Blocks
Figure 12 illustrates two precision-gauged setup blocks. These are used for precision application where the exact amount of force expended on the stop or bottom block must be known for process control and protection applications.

The Wheatstone full strain gage bridge is bonded around the holes in the center of the blocks. Note how the signal output wiring is brought out through armored cable for protection.

Non Calibrated Borehole Sensors
Some applications have been made of non-calibrated borehole sensors in pressworking applications. There is an opinion that detecting a change in the peak output signal is sufficient for process control. This information may be of very limited usefulness.

In the writer’s opinion, this is a slipshod way to apply instrumentation to control a pressworking process. It is reasonable to have a calibration procedure for all sensors. The output should be given in some standard engineering units such as tons or kilo Newtons.
Non Amplified Piezoelectric Load Cells
The same problem concerning needing very high input impedance applies to quartz load cells. The suppliers of the quartz load cells can also supply the appropriate electronic interface equipment or can recommend sources for the needed interface devices.

Quartz load cells are available with force capacities from a few ounces through 20 or more tons. Many off the shelf designs are called force rings because they are hollow. This style finds widespread application to measure the force required assembling bearings and other components onto shafts. They can also be built into dies under critical cutting stations to determine cutting forces within the force ring’s tonnage capability.

Time Constant Formula Application
Many shops adapt personal computers using data acquisition plug in cards for process control. Some of the best applications are developed in house. To determine the input impedance or resistance of the input device, the time constant formula should be applied, where:

\[ T = R \times C \]  

(EQUATION 1)

In this Equation:  
\[ T = \text{Time in seconds} \]
\[ R = \text{Resistance in ohms} \]
\[ C = \text{Capacitance in farads} \]

This formula gives the amount of time required for the voltage stored in a capacitor to discharge to 1/3 the initial value. For accurate waveform output, it is recommended that five time constants be allowed.

The capacitance of the piezoelectric sensor may only be on the order of 100 Pico farads. For practical uses in pressworking, either additional parallel capacitance must be provided or a charge amplifier having an input resistance on the order of 100 megohms or more must be used. Instrumentation applications for piezoelectric sensors are discussed in a number of references.  

A Clean Room for Strain Sensor Fabrication

2 R. Pallas-Areny and J. Webster, "Sensors and Signal Conditioning", John Wiley & Sons, Inc. New York, © 1991. See pages 247 to 259 for the theory and application of piezoelectric sensors. This book is highly recommended for the theory and signal conditioning requirements for the sensors. The book is well arranged in terms of sensor classes and considerations for interfacing the outputs so data can be acquired.

Figure 13. A photograph taken through a window of a modern clean room facility for gaging strain sensors. Toledo Transducers, Inc.

Cleaning a Strain Sensor Prior to Encapsulation

Figure 14. Solvent and a swab are used to clean the soldering flux from a precision strain sensor or “strain link” prior to environmental encapsulation. Toledo Transducers, Inc.

Strain Link Fabrication
Strain links are a special type of sensor when correctly bolted to a press or other machine housing provides an output proportional to the change in strain. The output can be computed directly in microstrain, which is the amount of strain change given in parts per million. The output can be provided in units such as tons or kilo Newtons. The change of strain occurring in the machine housing during operation is useful information when calibrated with precision load cells such as the ones shown in Figures 1, 2 and 5.

Precise repeatable construction of the strain links is an absolute necessity if interchangeability between the individual sensors is to be achieved. Figures 13 and 14 illustrate the clean room conditions and care with which the sensors are assembled. These strain sensors employ four foil strain gages in a Wheatstone bridge configuration.

**Strain Gage Application on Underdrive Press Pull Rod**

![Image of strain gage application on underdrive press pull rod.](image regarding underdrive press pull rod)

**Figure 15.** Example of a method of applying strain gages to a press pull rod. Note how the signal wiring is routed out through coiled plastic tubing. *Toledo Transducers, Inc.*

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4 Any drawings in this paper supplied by or photographs depicting the manufacturing processes of Toledo Transducers Incorporated of 6834 Spring Valley Road Holland, Ohio 43528 are identified as courtesy of Toledo Transducers, Inc. in the figure caption. The information is made available solely to inform users and potential users of Toledo Transducers, Incorporated. Some of the information is proprietary engineering data belonging to Toledo Transducers, Incorporated. These drawings may not be reproduced or used in any way detrimental to the interests of Toledo Transducers, Incorporated.
Figure 16. A simplified view of the toggle mechanism of the outer slide of an underdrive double action press. The toggle mechanism provides the dwell on bottom dead center required to hold the blankholder while the inner slide forms the part. 

*Courtesy of Toledo Transducers, Inc.*

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Strain States in Underdrive Press Toggle Mechanism

Figure 17. Diagram of the tensile, shear and compressive strain conditions that occur in an underdrive press. All strained locations are candidates for mounting strain sensors to actuate tonnage monitors. Courtesy of Toledo Transducers, Inc.

High Accuracy Load Monitoring on Underdrive Presses

Figure 17 shows the underdrive press mechanism and the tensile, shear and compressive strain conditions that occur. Many strained locations have been historically used for mounting strain sensors to actuate tonnage-monitoring equipment. The pull rods usually are connected to the crosshead or cross member. The lower drive mechanism linkage is attached to the crosshead and pulls the slide down when the press is cycled.
Underdrive press tonnage monitoring has been used for many years. Press manufacturers and users have been installing strain type tonnage sensors on a number of the highly strained locations shown in Figures 16 and 17 in order to determine press-operating forces. Because strain gage based load analysis can directly be measured simply by applying simple engineering formulas, the pull rods have proven to be the best location for accurate real time load data acquisition. The main difficulty has been maintaining the strain sensor wiring. Coiled rubber strain gage cords tend to fail in a year or less. A system of bringing the wiring out through coiled nylon tubing has overcome that problem.6

Example of Strain Gage Attachment on a Pull Rod

![Diagram](image)

Figure 18. A sectional view through an underdrive press pull rod showing the application of strain gages that are prebonded to a metal carrier. *Toledo Transducers, Inc.*

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Strain links such as illustrated in Figures 13 and 14 can be attached to pull rods. If two strain links are attached 180° apart on opposite side of the pull rod errors due to any bending or twisting of the rod that may occur are cancelled out by wiring the strain links in parallel.

Tapped holes and the heat of weld pad attachment are both objectionable because a stress-riser is created that may cause the pull rod to fail. Properly installed, spot-welded gages can provide a robust installation on moving press members. A less costly and far better method is the application of strain gages that are prebonded to a metal carrier shown in figure 19. These are attached with a 10 to 50 watt-second capacitive discharge spot welder. Attaching half the bridge circuit to either side of an eccentric strap or pull rod in the case of an underdriven press provides immunity to signal errors due to bending or twisting. The pull rod or eccentric strap is an excellent location for strain sensor mounting.

**Low Energy Spot Welding Metal Carrier Strain Gages**

![Figure 19](image)

*Figure 19.* Close up view of method of attaching prebonded strain gages to a pull rod. This method permits the wires to be soldered under laboratory conditions, which avoids performing this delicate work inside the press housing. *Toledo Transducers, Inc.*
It is recommended that a strain gage or sensor be applied to each side of the pitman and the sum of the readings used. This will essentially eliminate errors due to bending or twisting. Figure 8 illustrates a strain sensor applied to either side of a press pull rod. The sensors may be two Wheatstone bridge-type strain links connected in parallel. If the spot-weldable gages are used, two gages each making up half the bridge, are applied to either side of the pull rod as shown in Figure 18.

**Environmental Protration of the Strain Gages**

![Image](image.jpg)

**Figure 20.** After the strain gages are bonded to the pull rod, a sealing compound that will withstand years of exposure to lubrication oils and moisture is applied. Installations of this type typically last over ten years. *Toledo Transducers, Inc.*

**Good Routing of Signal Wiring a Key to Success**

A system used by Toledo Transducers of Holland, Ohio routes the signal wiring out through coiled plastic air hose, using electrical junction boxes and ordinary pipe fittings to terminate the mechanical attachments. Such installations provide trouble-free service for many years. Good gage attachment and encapsulation practices are an essential factor in a successful installation.

**Environmental protection of the Strain Gages**

A final step in installing spot weldable strain gages to a press member such as a pull rod is to encapsulate the gages in a sealing compound that will withstand lubricants and moisture. A properly encapsulated gage installation is illustrated in Figure 20.
Experience has shown that the press can be disassembled for maintenance including removal of the pull rods without damaging the strain gage installation. Ordinary care by plant maintenance technicians in disconnecting the signal wiring at the junction boxes and taping corrugated paperboard to the gage area is sufficient.

Of course, careful rigging and handling of any machine part is an important rule that must be followed whenever working on any power press. Common sense and skill in handling heavy machine parts avoids damage and possible injury to personnel.

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