BASIC PRINCIPLES OF PRESS FORCE MONITORS

Calculating the tonnage or force required for a pressworking operation can be done by careful analysis of the material properties and sequence of work done in the die. This is normally done by the die designer or tooling engineer in order to specify the correct press for the job. However, the tool engineer is not the person who is going to set up and operate the press. Changes in material properties, tooling wear and errors in engineering calculations can all cause the actual force requirements to vary greatly from calculated values.

Advantages of Force Monitoring

There are actually pressworking operations so precise that a mechanical engineering degree is a requirement to setup and operate the machine. However, the vast majority of presses are set-up and operated by persons having no formal engineering training. They have learned the job by experience.

Example of a Mechanical Force Monitor

![Diagram of a Mechanical Force Monitor]

**Figure 1.** A dial indicator mounted on a press column used as a mechanical force indicator. *Smith & Associates*

Force monitoring is an excellent pressworking process and control tool. It is an aid to achieving setup repeatability and pinpointing problems. To achieve maximum
utilization, training in the theory and operation of the monitoring equipment is essential. Essentially all modern force monitoring devices employ some form of mechanical displacement transducer that provides an electrical signal that varies in accordance with a change in strain or displacement. These devices are generally called strain gages, strain sensors, strain transducers, or strain links.

**Force Measurement Historical Development**

An old concept is the measurement of operating forces of presses. Hydraulic press forces are easily measured directly from the fluid pressure applied to the cylinder. Usually, the gauge is calibrated to indicate both the fluid pressure and the equivalent force based on the piston area.

The force developed by a single cylinder hydraulic press can be measured accurately. The main sources of error are attributable to friction in the cylinder packing and slide guiding method. The accuracy of the gauge must also be considered. If the press force is in the top third of the capacity range, actual gauge readings will typically be within 2% to 5% of a true reading.

The errors are likely to be greater at forces that are a small percentage of the press total force capacity. This is because friction in the cylinder is a larger percentage of the developed force. In addition, the pressure gauge accuracy is usually given as a percentage of full-scale reading. The accuracy of low gauge readings depends upon factors such as scale printing errors and how linear the mechanism is in mechanical gages.

**Mechanical Strain Measurement**

An old method for determining operating forces by means of measuring the displacement of a straightside press housing is illustrated in Figure 1. The housing or column together with the crown and bed are held in compression by prestressed tie rods. As the press is cycled through bottom developing force, the preload on the columns is partially relieved.

Either a dial indicator having built-in mechanical amplification or a vernier scale is used to determine the mechanical displacement of the press column. Practical dial indicator systems incorporate a second pointer to retain the peak reading. Vernier scales provided with a mechanical decoupling device to store the peak reading could be used.

This system was historically useful for press development and analysis of problem processes. It has been supplanted almost entirely by electronically amplified strain sensors.

**Early Electrical Strain Measurement**

Charles M. Kearns, Jr. is considered the inventor of the bonded electric resistance carbon strain gage. Prior resistance strain gages were carbon-base paints applied as liquids. Charles joined the Hamilton Standard Company in 1936 and was assigned the problem of correcting propeller blade fatigue stress failure in flight.
The strain gages of the day were either mechanical or carbon-base paints applied as liquids. Charles applied his amateur radio experience with carbon resistors to devise a better resistive gage. He simply ground a carbon resistor down and cemented it to a beam. He found as the beam was deflected, the resistor changed resistance with strain linearity.

This invention was put to use in late 1936 and enabled the development of better aircraft propeller designs. On the eve of World War II, it gave the Allies their first reliable means of measuring in-flight strains and resulted in superior aircraft designs.

The bonded carbon gage was used into the 1940s. It was supplanted by the resistive wire strain sensor simultaneously invented by Edward E. Simmons, Jr. and Arthur C. Ruge in 1939.

**Some Electronic Strain Sensors Used in Pressworking**

Several types of strain sensors are used in pressworking applications. Strain sensors provide an electrical signal that is directly proportional to the mechanical displacement being sensed.

The most familiar device for pressworking applications is the strain sensor or *strain link* used for tonnage monitor applications. The strain link has a rugged housing containing a calibrated assembly incorporating one or more strain gages. Most tonnage meter installations require one strain link per channel of information.

To provide a useful output, strain links or transducers must be installed on the press at a location where the change in reading is proportional to the change in tonnage in the die space. The most popular location on straightside presses is the press column upright. The strain transducer is also mounted to the frame of gap presses.

Most strain sensors mount by means of screw attachments and are generally interchangeable with another of the same type without need for recalibration. Several types of strain sensing elements are used to construct pressworking strain transducers.

**Foil Strain Gages**

The modern foil strain gage evolved from the resistive wire strain sensor simultaneously invented by E. Simmons and A. Ruge in 1939. An agreement to jointly share the patent was agreed. The patent negotiations and early production of the wire strain sensor was by the Baldwin Lima Hamilton (BLH) Locomotive Company.

The Baldwin Lima Hamilton interest in the strain gage had several driving factors. BLH management was diversifying their product line from locomotive production to include both large power presses and mechanical testing machines. The testing machine calibration and measurement made good use of the tiny strain gages.¹

Peter G. Scott Jackson is considered to have invented the modern bonded electric resistance foil gage in the early 1950s. Like the early bonded carbon gage. The foil gage was developed out of necessity to aid helicopter blade research and development. BLH electronics was also very instrumental in the development and mass production of the foil gage. A modern bonded foil gage is illustrated in Figure 2.

**Figure 2.** A modern BLH Electronics foil strain gage. The term SR - 4 makes reference to the inventors of the earlier wire gage, Simmons and Ruge.

Frank Tatnall, a key figure at BLH, joined The Budd Company in 1956, to apply the strain gage to their emerging testing machine business. The Budd Company continued to serve as a leader in applying instrumentation to control the sheet metal forming process under Dr. Stuart Keeler and Michael Herderich.  

The foil strain gage is one of the most widely used components for constructing strain sensors for press tonnage monitor applications. The foil, generally a copper-nickel alloy known as constantan, is very thin. It is supported by a thin plastic substrate. The nominal resistance of most gages is 350 ohms. As the gage is stretched or compressed, the resistance increases or decreases by a slight predictable amount due to the change in the length and cross-sectional area of the gage foil tracks.

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2 M. Herderich, "Experimental Determination of the Blankholder Forces Needed for Stretch Draw Design", SAE Paper 900281, Warrendale, Pennsylvania, © 1990. Herderich has done extensive work on gathering strain gage data on a variety of presses within Budd Company. One conclusion of the paper is that more force is required to prevent a biaxial stretch forming lock bead from slipping than that required to form the bead if no stretching action occurs.
The amount of resistance change per length movement is predictable, and termed gage factor. Gage factor is defined as:

\[
GF = \frac{\Delta R/R}{\Delta L/L}
\]  

(Equation 1)

In this Equation: 
- \( R \) = Unstrained resistance in ohms
- \( \Delta R \) = Strained resistance in ohms
- \( L \) = Unstrained gage length
- \( \Delta L \) = Strained gage length

### Wheatstone Bridge Strain Link or Sensor Circuit

To provide a balanced output having high noise immunity and ease of connecting to instrumentation amplifiers, the usual practice is to use four gages connected as a Wheatstone bridge circuit. Two diametrically opposite gages are installed in line with the strain to be measured. The other two are installed at a 90-degree angle to the first set to measure the change in width. These gages are installed on a small metal structure, which is housed in a rugged enclosure. This makes up the strain sensor or strain link.

#### A Wheatstone Bridge Strain Gage Circuit

![A Wheatstone Bridge Strain Gage Circuit](image)

Figure 3. A Wheatstone bridge circuit used for constructing bonded foil strain gage strain sensors or transducers. \( R_1 \) through \( R_4 \) are each typically 350 Ω strain gages. \( V \) is an external DC voltage source of typically 12 to 16 volts balanced to ground. The output \( V_o \) is typically a few millivolts. \( R_c \) is a calibration resistor contained in the tonnage monitor.
A typical resistance value for $R_c$ is 100,000 $\Omega$. This resistor is temporarily shunted across $R_3$ by means of a switch in the tonnage monitor. This will deliberately establish an imbalance in the Wheatstone bridge circuit and provide a reading on the tonnage monitor. The reading is proportional to the amount of gain or amplification, which is adjusted to provide correct rereading. This *calibration number* recorded inside the tonnage monitor enclosure. The calibration number is needed to recalibrate the tonnage monitor in the event the gain is inadvertently changed.

**Semiconductor Strain Gages and Sensors**

The advantage of semiconductor strain sensors compared to metallic foil types is that much greater output (typically ten or more times that of foil strain gages) is obtainable. Load cells using semiconductor sensors were pioneered in the early 1960s for the United States Space program by Bytrex, (now Data instruments).

Strain links for press force monitoring employing silicon semiconductor strain sensors are available with built-in amplification. The high gage factor, together with built-in differential amplification, provides very high output and excellent immunity to electrical noise pickup.

**Piezoelectric Sensors**

A third type of strain link used for press tonnage meters makes use of a piezoelectric material, such as quartz. The strain link provides mechanical protection and electrical isolation for the piezoelectric material. A mechanical mounting connection to permit attachment to the machine is also provided. The output is a voltage proportional to the force impressed across the faces of the sensor.

This sensor requires no external power supply for operation. Its output is a large voltage proportional to strain. This high-level signal has excellent noise pickup immunity. Since the sensor can supply virtually no current, the tonnage meter incorporates a *charge amplifier* to drive the meter circuitry.

**Measuring Press Strain to Determine Force**

Accurate force monitoring requires the strain gages or sensors be placed on the press at locations where the strain being measured throughout the machine cycle is equal to the force being developed. In addition to a linear force to strain relationship, the location should exhibit large strains and be as free as possible from mechanical noise.

**Attachment of Strain Gages and Sensors**

Long-term stability requires the use of high quality adhesives. In addition, considerable skill is required to install strain gages correctly.
Depending on the part of the press being gaged, it may be necessary to remove the machine from service to allow overnight curing of the adhesive. This need to remove the press from service is often not possible.

For ease of maintenance and replacement of a damaged sensor, interchangeable bolt-on strain sensors, called strain links are often used. The strain sensing elements are installed in a laboratory environment and carefully calibrated for equal output from unit to unit. Should a strain sensor be damaged, it can easily be replaced with an interchangeable unit.

Tapped mounting holes are provided at the point of attachment of the strain link. A second method is to attach pre-threaded pads by welding. In either case, it is recommended that a drill or welding jig be used to obtain accurate hole spacing. In case of misalignment, the strain sensor will be distorted and give a false output. Should this occur, the force-indicating monitor may not be adjustable to zero output.

Another method is the application of strain gages that are pre-bonded to a metal carrier. A useful material for this application is 300 series stainless steel approximately 0.005 inches (0.127 mm) thick. Strain gages can be prebonded onto the stainless carriers using thermal setting cements having long-term stability and prewired.

These prewired sensors are attached with a small portable capacitive discharge spot-welder operating in the 10 to 50 watt-second range. Attaching half of the bridge circuit to either side of a pitman or, pull rod in the case of an underdriven press provides immunity to signal errors due to bending and/or twisting.

**Pitman Sensor Locations**

The pitman or eccentric strap is an excellent location for strain sensor mounting. 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 of the pull rod or pitman.

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3 Hands-on workshops, and extensive technical information on strain gage installation, and environmental protection, including a full line of strain gages and installation supplies, are available from the Measurements Group, Inc., Raleigh, North Carolina.

4 B. Mettert, "Load Sensor Placement and Tonnage Data for Underdrive Presses", SME Technical Paper MS90-384, Society of Manufacturing Engineers, Dearborn, Michigan, 1990. This paper explains in detail the benefits; techniques and advantages of mounting metal carrier strain gages on under driven press pull rods compared to other methods. This procedure is extensively used by Ford Motor Company.

5 Published proceedings, educational and reference materials of the Society for Experimental Mechanics, Bethel, Connecticut. Membership in this society is highly recommended for anyone working with strain gage based measuring devices.
Figure 4 illustrates a strain sensor applied to either side of a press pitman. The sensors used may be a two Wheatstone bridge type strain links connected in parallel. If the spot-weldable gages are used, two gages, each making up half of the bridge are applied to either side of the pitman.

The latter split bridge method is less costly than using two strain links in parallel to avoid errors due to any bending and twisting of the pitman. It also avoids tapping holes in, or placing weld-pads on the pitman, which would tend to create a stress concentration point.

Both tapped holes and the heat of weld pad attachment are objectionable, because a stress-riser is created that may cause the pitman to fail. The small capacitive discharge spot welds used to hold the split bridge sensors in place are not considered to create a harmful stress riser.

Properly installed, spot-welded gages can provide a robust installation on moving press members. A system used by Toledo Transducers of Holland, Ohio is a good example. The signal wiring is routed through coiled plastic air hose and terminated in standard electrical junction boxes.

**Strain Sensors Installed on Opposite Sides of a Pitman**

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*Figure 4.* A strain sensor applied to either side of a press pitman: the signal wiring is brought out through coiled plastic air hose, using an electrical junction box and pipe fittings. *Smith & Associates*
One method to attach the junction box to the pitman is by using steel band strapping. Such installations have provided trouble-free service for many years. Good gage attachment and encapsulation practices must be followed. Information on strain gage applications and installation techniques are available from references 3, 4 and 5.

**Straightside Press Column Mounted Sensors**
The columns or uprights of straightside presses are popular locations for mounting tonnage meter strain links. Ease of installation is the main advantage, compared to placing sensors on the moving press pitman.

**Good Vs Poor Sensor Mount Locations**

*Figure 5.* Strain sensors should be mounted on the inside of the columns (L2) where possible because the bed and crown deflection tends to drive the outside of the column into compression; a factor that introduces waveform distortion and results in low output when mounted on the outside (L1). *Smith & Associates*

**Case Study of Poor Sensor Mounting**
For many years, some tonnage meter installers have routinely mounted the sensors on the outside of the columns. This location is convenient. In addition, the sensor may be better protected from damage than if mounted in the die space of the press. However, this may not be the best location for good process monitoring if the pitman is not accessible. Figure 5 illustrates why this location is often not preferred.

Strain sensors should be mounted on the inside of the columns in line with the center of the bed (L2), where possible because the bed and crown deflection tends to drive the outside of the column into compression. This results in low sensor output.  

Controlled tests conducted on four straightside presses at Webster Industries, located in Tiffin, Ohio involved moving all strain sensors from the outside to the inside of the columns. Carefully documented increases in sensitivity averaged from 236% to 694% per press.

Installing the sensors in the inside of the column near the crown is another useful location if the inside of column location is not available. For example, on some presses the tie rod shroud is not accessible in the inside of the column because of a structure to permit gravity return of the gibbing recirculating lubricating oil.

The reason for moving the sensors was to obtain valid chart recorder waveform signatures needed for die-timing analysis. The data is successfully being used in a snap-through reduction program.

**Example of Poor Mounting Location**

The first waveform signature was made on the 500-ton (4448 KN) straight-side Minster press during a heavy punching and cut-off operation. There was no timing of punch entry, so a signature of a gradual force buildup followed by a severe reverse snap through load was expected. Figure 6 illustrates the waveform signature that was actually recorded.

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8 D. Smith, Video, “Quick Die Change”, divided into 26 training sessions, referenced material includes workbooks and facilitator's guide, Society of Manufacturing Engineers, Dearborn, Michigan, © 1992. The bed deflection and column decompression phenomena discussed in references 7 and 8 are animated in tape five.

9 Controlled tests conducted by the writer at the W. C. McCurdy Company, Troy Michigan in 1989 on straightside presses showed a clean signal and an improvement in output of 4% to 25% by moving the sensor to the inside top of column location.
Example of A Bad Signal Due to Poor Sensor Location

Figure 6. Poor waveform fidelity results from mounting strain sensors in poor locations. 

Smith & Associates

The tonnage increase started at (A) when the punches made initial contact with the stock. Plastic deformation of the stock occurred as the punches penetrated the stock until point (B) is reached where the punches broke through the stock. The sudden release of energy that occurred when the punches broke through causes a negative load (C) to occur. This energy sets up a mechanical oscillation within the press resulting in a positive peak at (D).

According to accepted theory, the oscillation should decrease in amplitude over a few cycles. This was not the case. A higher peak (E) than the force that caused it (B) is seen. This is followed by negative peaks (F) that exceed the amplitude of the initial snap-through at (C).

Analysis of the Problem

Upon comparing the peak voltage levels recorded on the chart with the tonnage values displayed on the tonnage meter, it was found that the chart recorder voltage levels were low by a factor of three. It was found that the press capacity set inside the tonnage meter by the electrical contractor who installed it was 1,500 tons (13,344 KN) rather than 500 tons (4448 KN).
This is an unacceptable practice in the writer’s opinion. The reason that this is sometimes done is to get enough strain gage amplification to display correct readings. The root cause of low strain gage output when measuring loads on mechanical presses is because the gage or transducer is mounted at a location on the machine that sees little strain under normal press operation.

A poor sensor location will result in a reading that displays the peak vibration level rather than the peak force. The writer has found a number of such installations where striking the press column at the base with a hammer several feet (1 meter) from the sensor would drive the tonnage meter readout off scale. In such cases, the tonnage monitor is measuring vibration levels rather than force developed by the pressworking operation.

**Plan Cross Sectional View of Minster 500 Ton Press**

![Plan Cross Sectional View of Minster 500 Ton Press](image)

**Figure 7.** Mounting locations for strain sensors on the column of a Minster 500-ton (4448 KN) straightside press. *Smith & Associates*

Figure 7 illustrates a horizontal cross section through the press columns. The four tie rods are each surrounded by a shroud made of heavy steel plate. This part of the column structure is designed to withstand the compressive preloading that the tie rods exert on the column.

The rest of the vertical steel plate in the column is much lighter. The main design consideration for the lighter plate is to provide enough rigidity to withstand the lateral forces generated during normal press operation, and to provide a housing for mechanical and electrical equipment.
The strain transducers were mounted by the electrical contractor at (L1) shown in Figure 7. This was probably done because the location was easily accessible. An assumption that it doesn't matter where strain transducers are mounted so long as a load cell calibration is performed may have been made. This assumption is not correct. By mounting the sensor on the lightweight plate, the main thing that was being measured was the magnitude of the mechanical resonance or oscillation excited by the snap-through release, not the actual forward and reverse loads.

Waveform Signature of Good Vs Bad Sensor Location

Figure 8. The upper waveform signature was obtained from a strain sensor mounted at (L1) in figure 5. The lower waveform signature was from a sensor mounted at (L2).

Correcting the Sensor Location Problem

The tonnage meter manufacturer was contacted for advice on correcting the problem. Even though the installation was done by an independent electrical contractor recommended by a press equipment dealer, and the equipment was out of warranty, the manufacturer was more than willing to provide all of the needed technical support to correct the problem. This included an on site evaluation by the president of the company and the manager of the technical support group.
It was clear that a better sensor location was needed. A strain transducer was mounted at location (L2) (Figure 7) and the signal fed into a channel of the tonnage meter which was adjusted to the same calibration number or gain setting as the sensor at (L1).

An A-B comparison of the two side-by-side signals is shown in Figure 8. The upper trace is from the sensor at (L1) and was made on the 2.5 volts full-scale range. The lower trace is from the sensor at (L2) and was made on the 5 volts full-scale range.

The improvement in sensitivity measured at the peak load that occurred just before snap-through is a factor of 3.45. This improvement in sensitivity permitted the tonnage meter to be operated at the correct press capacity setting. Note that the lower trace is much cleaner than the upper trace indicating that the ratio of electrical noise pick-up to the desired signal was also improved.

Location (L4) shown in Figure 7 was also tried and the sensor reading approximately doubled over location (L2). Locations on the inside of press columns are usually much more sensitive than those on the outside of the column. This is because both the press bed and crown deflect. The tie rod nuts act as neutral points. The result that the outside of the columns tends to be driven into compression while the preload is rapidly relieved on the inside of the columns. How this phenomenon occurs is shown in Figure 5.

**Sensor Mount Locations on Other Presses**

The same problem was encountered on the other three presses that had tonnage meters. Apparently, to simplify the routing of wiring, the contractor had installed the sensors on the outside of the columns. Moving the sensors to the inside of the columns resulted in the improvements in sensitivity listed in Table 1.

<table>
<thead>
<tr>
<th>PRESS</th>
<th>PERCENTAGE IMPROVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 ton Minster</td>
<td>694%</td>
</tr>
<tr>
<td>300 Ton Verson</td>
<td>294%</td>
</tr>
<tr>
<td>300 Ton Verson</td>
<td>430%</td>
</tr>
<tr>
<td>250 Ton Verson</td>
<td>236%</td>
</tr>
</tbody>
</table>

**TABLE 1**

**Improvements of in House Skills at Webster Industries**

The permanent location for all strain sensors used on Webster Industries presses is on the inside of the press columns. Electrician Dan Scholl is also a skilled electronics technician. He completed a two-year degree program in electronics technology at a local community college. The theory and operation of strain gages was a part of that training.

At management's request, a one-day hands-on training session in the correct installation and calibration of tonnage meters was conducted by the writer. This included how to do an accurate load cell tonnage meter calibration. A 250-ton (2224 KN) load cell was purchased for use with an existing portable tonnage meter for this purpose.
The result is that Webster now has an in-house tonnage monitor maintenance and calibration capability. This factor has greatly increased the confidence employees have in the tonnage meter data. Whenever a problem is suspected, Scholl can quickly resolve the issue.

Webster also has a Portland, Oregon stamping facility. Based on the success achieved with correctly installed tonnage monitors at the Tiffin, Ohio plant, tonnage monitors were purchased for the Portland facility. Dan Scholl was loaned to the Portland plant where he successfully installed and calibrated the tonnage monitors at that plant.

**Gap-Frame Press Sensor Locations**

Generally, the pitman is the preferred location for strain sensors on gap frame presses. However, like the straightside press, ease of installation considerations has resulted in the frame being the most frequently used location.

Measuring the tensile strain on the side of C-frame throat opening is extensively used. A more sensitive location is often found on the vertical frame at the back of the machine, in line with the center of the throat opening. Here, compressive strains are measured that are typically 40% to 70% greater than those measured at the throat opening. This is because the press builder takes advantage of the fact that a smaller cross sectional area will withstand higher compressive Vs tensile loads present in the throat area.

In other words, cost effective machine design takes advantage of the fact that iron and steel will withstand far higher loads in compression than in tension. Economy of design of gap-frame presses considers this. Therefore, the compressive strains seen at the rear of the machine are greater than the tensile strains at the front of the press.

The sensor may be mounted on the center of the rear edge of the plate or casting making up the machine frame if possible. Side of frame locations may sense strains attributable to bending. Properly installed, the rear of frame location generally provides a strong waveform signature. However, the side of throat opening location does show a true tensile load representative of the load in the die space.

**Gap-Frame Press Load Placement**

Once the tonnage meter is calibrated, it is important to place the pressworking load directly under the center of the slide connection. Placement toward the rear of the throat opening will result in less strain on the frame, and erroneously low meter readings.

Placement of the die forward of the connection results in readings that are err on the high side. In each case, the tonnage meter is reading actual strains in the frame.

However, this is not the load seen by the pitman and crankshaft. This source of error can be avoided by installing the strain sensors on the pitmans of gap-frame presses wherever possible.
Gauging Under-Driven Presses
Measuring the strain on the pull-rods of under-driven presses can be accomplished in the same way as pitmans are gaged on top-driven machines. In the author's opinion, the best installations make use of foil-backed spot-weldable strain gages. Attaching half of the bridge circuit to 180 degree opposite sides of the pull rod cancels out errors due to twisting or bending. This procedure is explained in detail in reference 4.

Strain gages provide very accurate direct readings of mechanical displacement. When applied to underdriven press pull rods of known material composition and dimensions, the true load for a given strain can be measured within plus or minus 2%.

Compressive Loads on Pull-Rods
When analyzing tonnage meter and waveform signature data taken from under-driven presses, it is not unusual to observe the pull rod being driven into compression. This is normal during the beginning of the upstroke of stretch draw operations that use large die cushions or nitrogen pressure systems for blankholder pressure.

The energy stored in the blank-holder pressure system, less frictional losses, is being restored to the flywheel in this case. If a large compressive load is observed as the press passes through bottom dead center, it is important to make sure that the reverse loading of the press gear train is not excessive when gear-tooth clearances are taken up in the reverse direction.

A correctly adjusted machine with proper die placement should show nearly equal loads on all the pull rods. Unequal pull rod load sharing indicates a machine alignment or incorrect die placement problem.

Under-Driven Press Alignment Problems
In the case of four point machines, low readings across diagonally opposite corners indicate an alignment problem. This may occur without a die in the press. In severe cases, the low reading pull rods may actually be driven into compression during a portion of the stroke, while the diagonally opposite pair may be overloaded.

When diagonally opposite corners indicate low or reverse loads it indicates that the machine is running in a severe bind due to misalignment or broken press parts. The machine should be removed from service and inspected. The bed should be checked for a skewed condition. The gear timing should be checked. Often, all that is wrong, is the drive timing to the slide adjusting screws is out of adjustment.

Double-Action Presses
For drawing and stretch-forming operations, both top-driven and under-driven machines built with double-actions are used. In each type, an outer slide or blank holder dwells on bottom of stroke to hold the edges of the blank, while the inner slide cycles through bottom dead center to draw or form the part.
Again, the pull rod location is highly recommended for strain sensor installations on double-action under-driven machines. Installing dual or split-bridge sensors on opposite sides of the pitmans or eccentric straps of top-driven double action presses is recommended.

Some installations of column-mounted sensors have been made on top-driven double action presses. The column load change produced by the outer and inner slides must be separated by cam signals. Then, the outer slide reading must be subtracted from the inner slide load. In practice, this is difficult to accomplish accurately, and is not recommended.

**General Sensor Location Considerations**

A strain gage or sensor can only measure the actual strain where it is placed and in the direction of strain to which it is sensitive. Strain sensors mounted on the columns, slide or press bed does not, in the authors opinion, give as accurate information of press loads as the pull rod or pitman locations.

**NOTES:**

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