

*Chapter 4*

# INSPECTING & REPAIRING MAJOR COMPONENTS

“Major components” discussed in this chapter include the press **main cylinder**; front or “resistance” **platen**; **tie rods** or **columns**; **container holder**; and **moveable crosshead**.

Extrusion presses experience cyclic loadings ranging into the millions of cycles. A press operating with 2-minute cycles, 120 hours per week will undergo a million cycles in less than 6 years. Since many presses in use today have operated at even greater frequency for 25 to 40 years, it is clear why high-cycle fatigue loading is a critical issue for extruders.

An excellent reference on this subject is the paper (reprinted beginning on page 4-25), **“Adapting Extrusion Presses for a High Cycle Fatigue Load Environment,”** by J.O. Nøkleby, of Det Norske Veritas. It provides a thorough discussion of the inspection, predictive maintenance, and repair of major press components. It was first presented by the author at the AEC Press Maintenance Seminar, in , , and is reprinted here with his permission. It is recommended reading for all extrusion plant engineers and managers, as a reference in developing a press maintenance program. We strongly recommend a careful reading **before, not after**, you experience a failure of a major press part.

By way of summary, we offer the following brief outline of major component maintenance and repair.

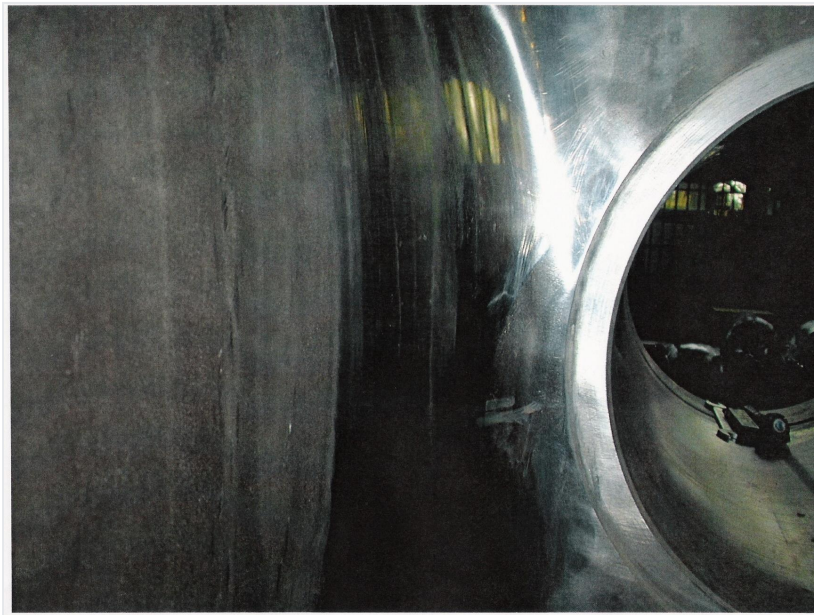


Figure 4-1: Polished Radius of Main Cylinder Photo courtesy of Presezzi Extrusion

**Definition of Fatigue.** Fatigue is the failure of materials under the action of repeated stresses. The applied stresses may alternate between equal positive and negative values, from zero to maximum positive or negative values, or between positive or negative values<sup>1</sup>. For a given material, fatigue life is expressed in terms of the number of stress cycles, which is a function of the degree of stress applied. A fatigue resistance diagram is constructed from test data to indicate the life cycles which may be expected according to the stress level.

Surface defects such as roughness or scratches, and notches and shoulders, all reduce the fatigue strength of a part.

Fatigue failure is manifested by gradual or progressive fracture, usually beginning as invisible cracks that progress in size until a disastrous failure occurs. In the early stages, progress of cracks is usually very slow.

Since all extrusion presses are subject to eventual fatigue failures of the major structural parts, it is wise for extrusion plant engineers and managers to understand this problem and to establish a program to:

- detect fatigue cracks
- monitor their progress
- make appropriate repairs where necessary and possible
- plan for eventual replacement in an orderly and timely fashion.

**Detecting Fatigue Cracks.** For presses in which cracks have not previously been detected, an annual inspection is recommended for components which are accessible without disassembly. Each 5 years, a more detailed inspection including the interior of the main cylinder is recommended.

There are several types of non-destructive examination (NDE) that may be used for detecting and monitoring fatigue cracks and other failures of press components<sup>2</sup>:

- visual
- ultrasonic
- magnetic particle
- liquid penetrant
- infrared thermography
- eddy current
- radiography (x-ray)

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1. MacGregor, Charles W., "Mechanical Properties of Materials," Marks' Mechanical Engineers' Handbook, Sixth Edition, McGraw-Hill Book Company, Inc., Page 5-11.

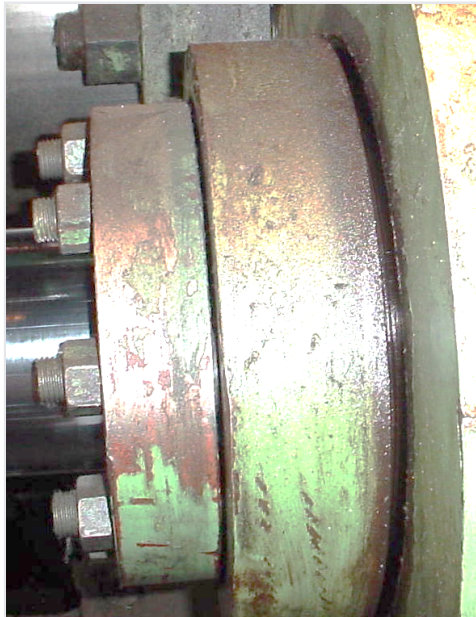
2. Manganello, Ron, Carlesa NDP, presentation to AEC Press Maintenance Seminar, Atlanta, November 2012.

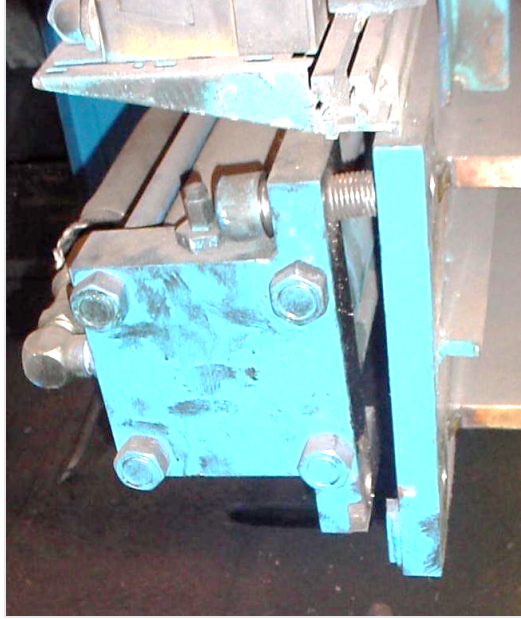
These methods (other than visual) are sophisticated and require expensive instruments and training in their proper use. For most small extruders it will be most economical to use the inspection services of a specialized contractor, of which several are available. However, in multi-press companies, or those with presses requiring frequent testing (in advanced stages of failure), it is recommended to consider establishing in-house testing capabilities.

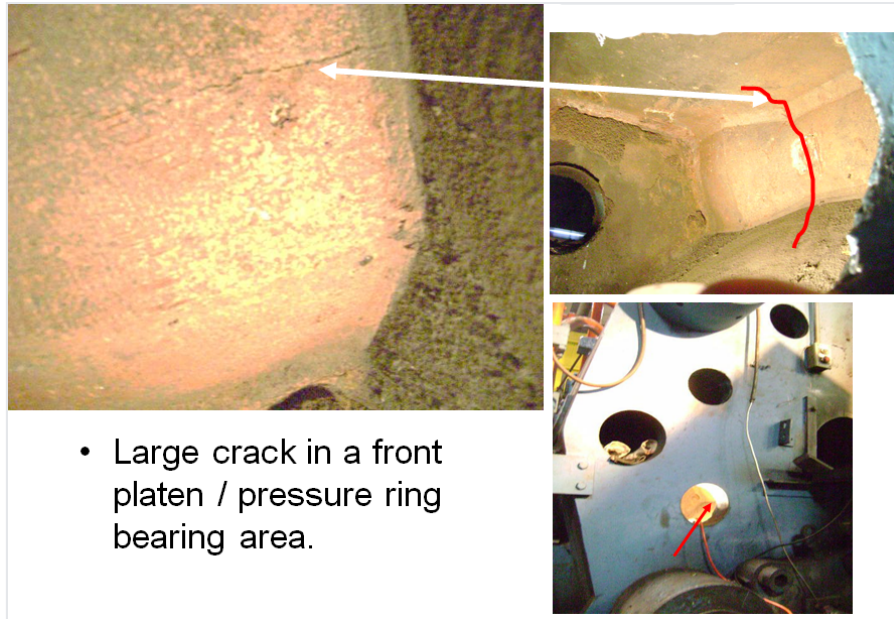
Examples follow of the inspection methods most commonly used on press components.

**Visual Inspection** is the primary method used for extrusion presses. Look for loose or missing components, oil leaks, or cracks.

Examples of items found by visual inspection: Loose side cylinder Detached die slide cylinder Oil leak, cracks







**Ultrasonic inspection (UT)** is the most sensitive technology for detecting subsurface flaws. It can detect extremely small flaws such as cracks at great depths. It can evaluate the thickness of an object to determine if there is corrosion. Ultrasonic needs only one accessible surface.



Ultrasonic indication of a tie-rod crack

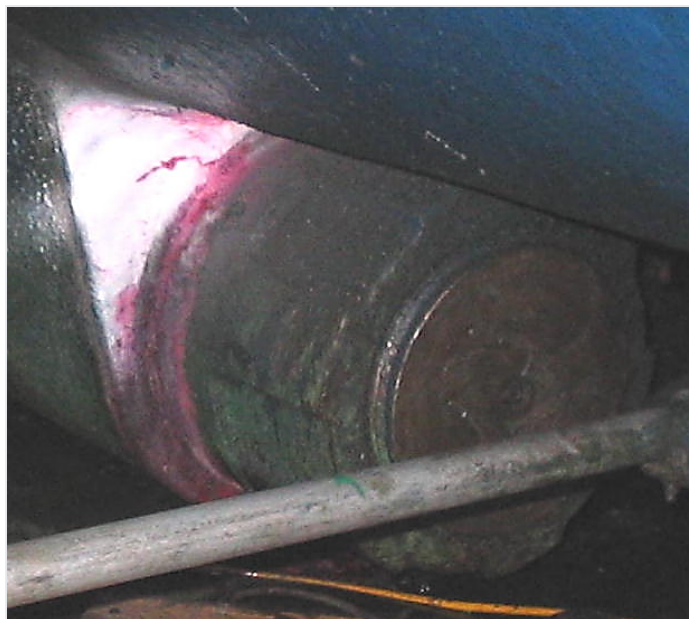
**Magnetic particle (MT)** first magnetizes the surface, after which colored magnetic particles are spread over the surface. If there is a crack or other flaw, magnetic particles become attracted to and build up along the area of the defect.

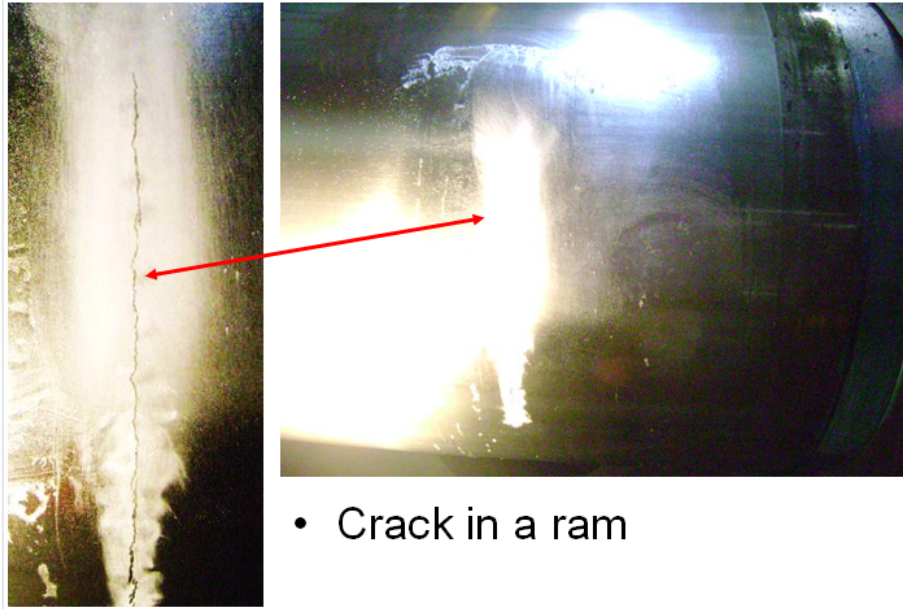


Magnetic particle shows cracks in a hot container housing

**Liquid penetrant (PT)** is often used on materials where magnetic particle examination is difficult to use. The examination surface is first cleaned, a red dye is placed on the area of interest, then a white developer is sprayed onto the surface. The developer draws the dye into the surface defects. If a colored dye appears, that indicates the position of the flaw.

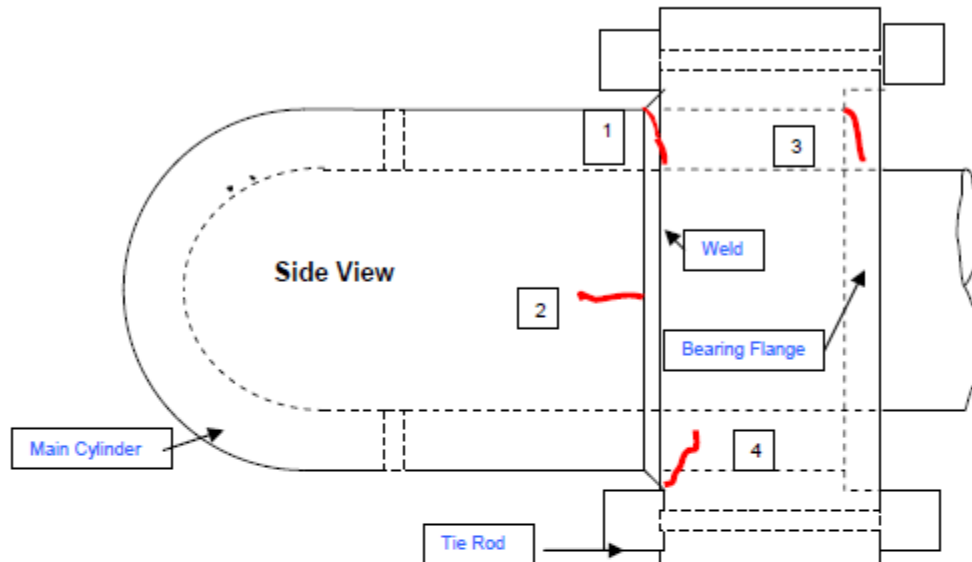
Examples of liquid penetrant (PT) tests Crack with red dye penetrant Leaking oil acting as a liquid penetrant





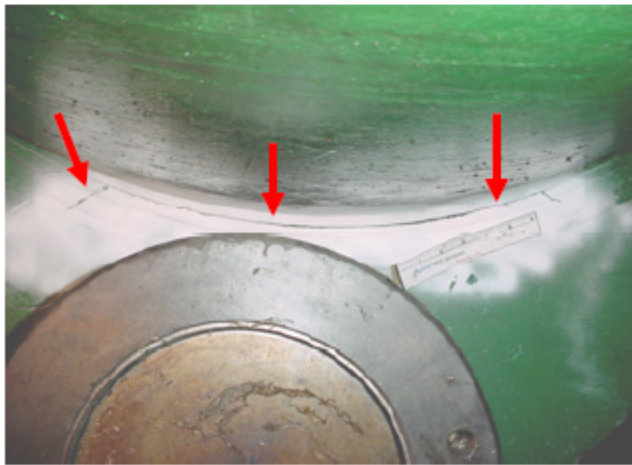
### Outside Surface Examinations

Outside surfaces are cleaned, and examined visually, and with the Ultrasonic, and Magnetic Particle, or Liquid Penetrant methods.



**Figure 6.** Common outside surface crack locations in hydraulic cylinder pressure walls.

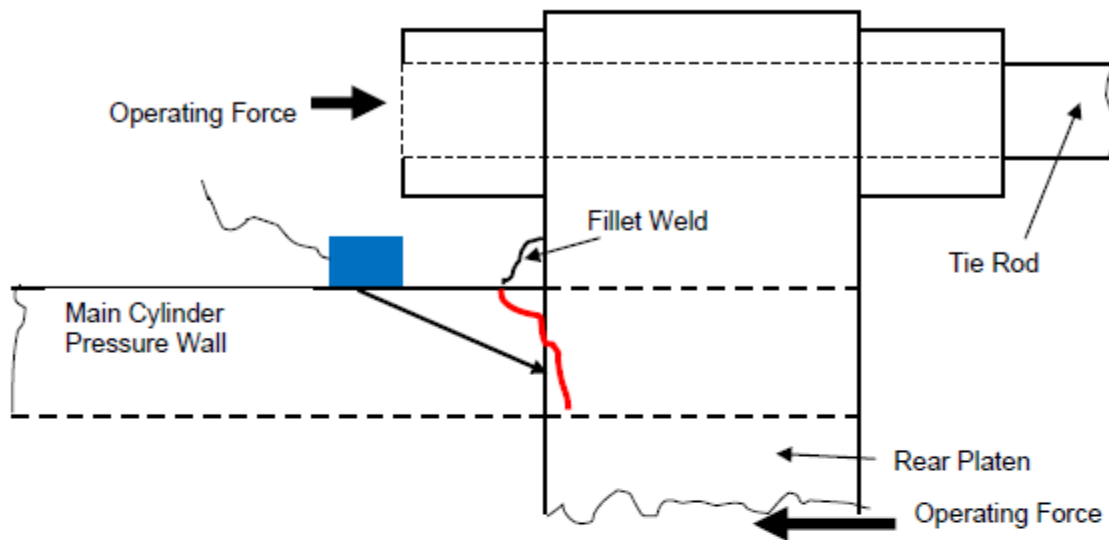
The diagram above (Figure 6) shows the most common locations for outside surface cracks. The picture below shows a liquid penetrant indication of a crack, as diagrammed at Figure 6, Position 1.



These cracks initiate at the rear-platen-to-shell weld edges on the shell side.

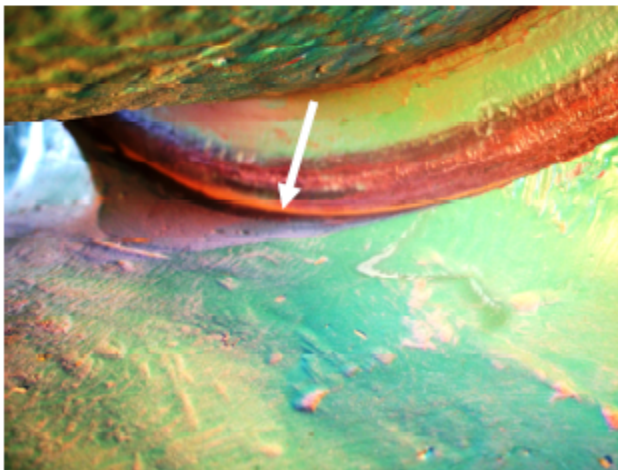
**Figure 7.** PT indication of a large crack from Figure 6, Position 1.

## Outside Surface Examinations



**Figure 8.** The diagram above shows a more detailed view of the crack shown in Figure 6, Position 1, and in Figure 7. UT angle beam techniques are used to measure the cracks' through-wall depth.

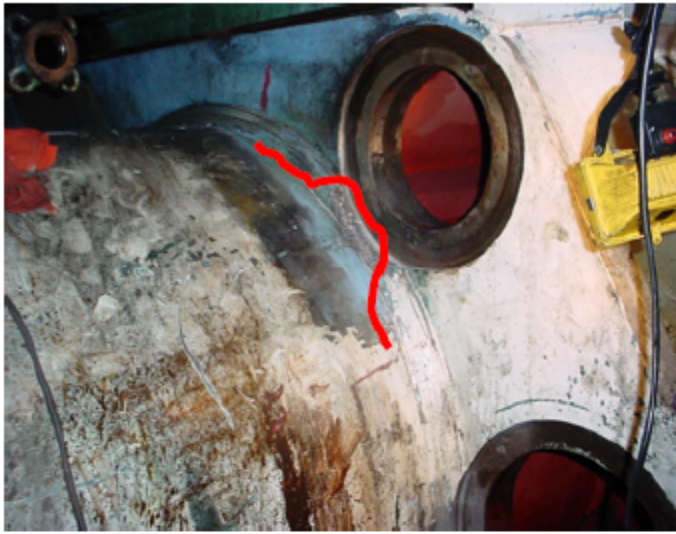
Similar cracks initiate at tie rod nut bearing seats, and can propagate into main cylinder pressure walls, shown in Figure 6, Position 4.



The picture to the left shows a magnetic particle indication of an initial stage crack in a tie rod nut seat in a rear platen/main cylinder casting, from Figure 6, Position 4.

**Figure 9.** An MT indication of a crack, from Figure 6, Position 4.

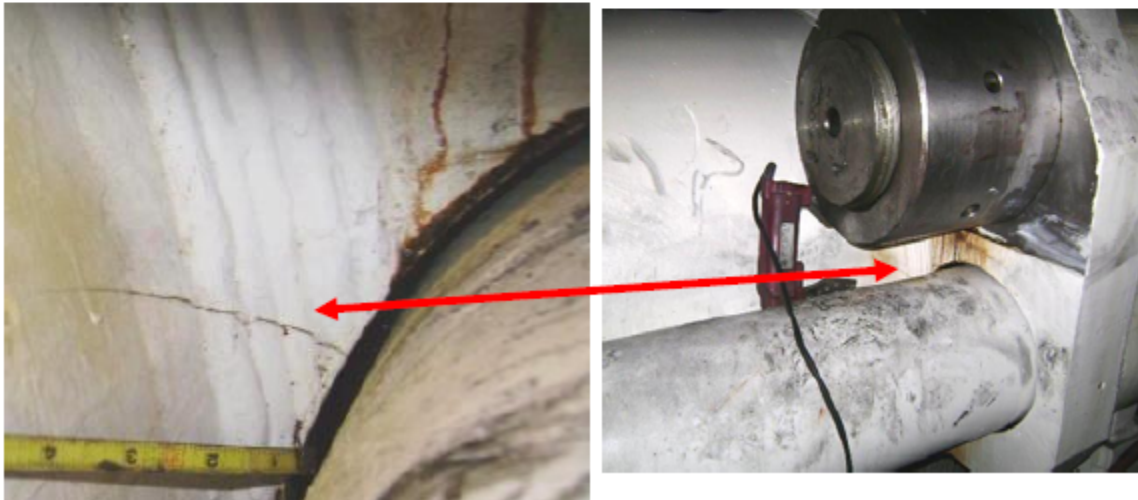
### Outside Surface Examinations



The picture to the left shows an enhanced magnetic particle indication of a large crack that had initiated at the tie rod nut seat (Figure 9), and had penetrated through the pressure wall. This crack occurred in a rear platen / main cylinder, fabricated of a forging and welded steel plate. The crack was excavated away, and the area was repaired by welding in Figure 6, Position 4.

**Figure 10.** The press shown above was disassembled to repair the through-wall crack highlighted in red.

Cracks, as diagrammed in Figure 6, Position 2, can initiate at corners of side cylinder penetrations in the rear platens. The pictures below show a crack that initiated at a sharp corner, and propagated 30 percent through the thickness of the pressure wall of the main cylinder.

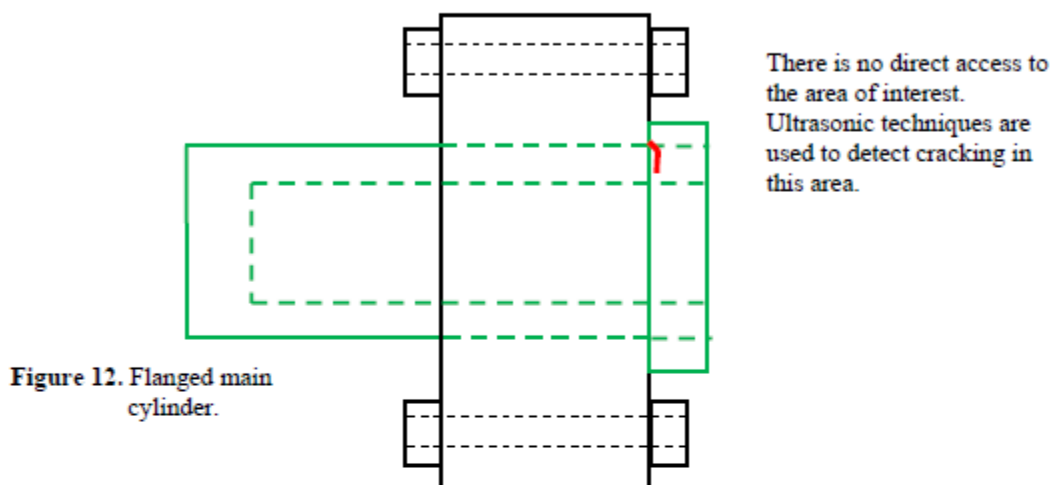


**Figure 11.** PT indication of a large crack from Figure 6, Position 2.

## Outside Surface Examinations

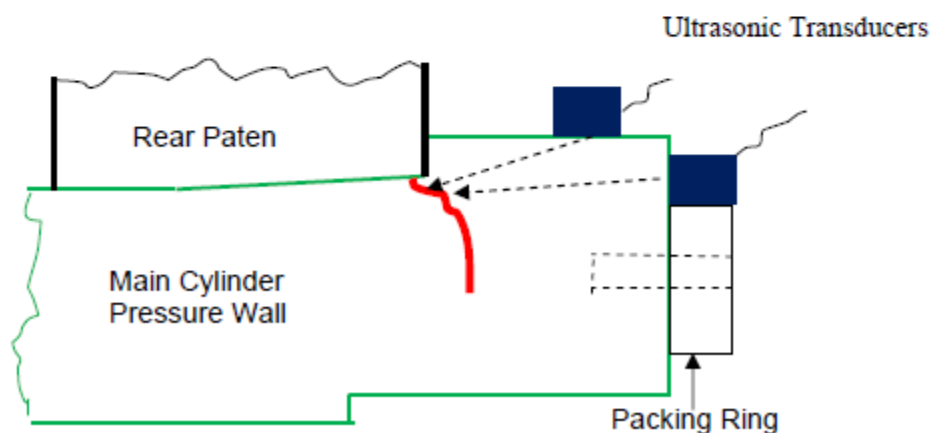
### Flange Cracks

More difficult to detect are cracks that initiate at the load-bearing flanges (Figure 6, Position 3). This problem is limited to main cylinders that are separate components from the main platens.

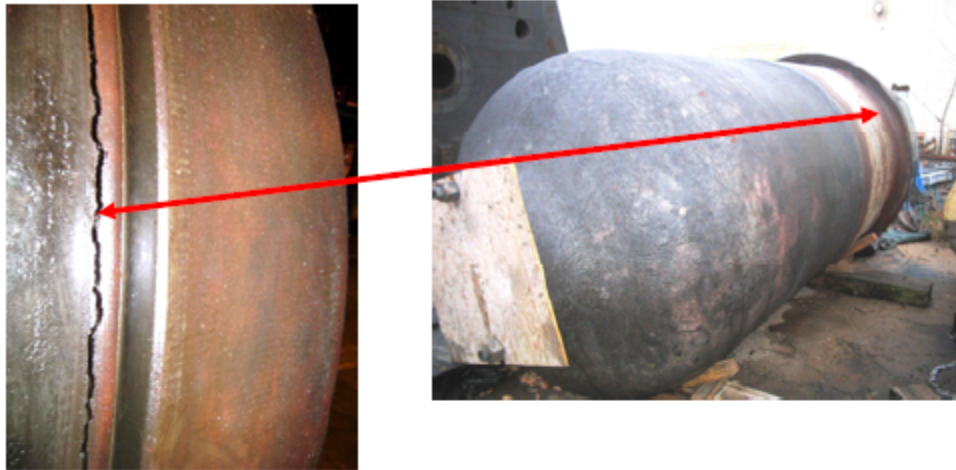


**Figure 12.** Flanged main cylinder.

Cracks in load-bearing flanges are detected with UT straight and/or angle beam techniques, applied from the accessible flange surfaces. Initial stage cracks can be oriented at angles other than perpendicular to the pressure wall thickness. In the early stages, these cracks can be resolved with angle beam techniques. Deeper cracks can be measured with a straight beam technique applied from the front face of the cylinder flange. Measurement of deeper cracks requires that the gland packing ring be withdrawn.

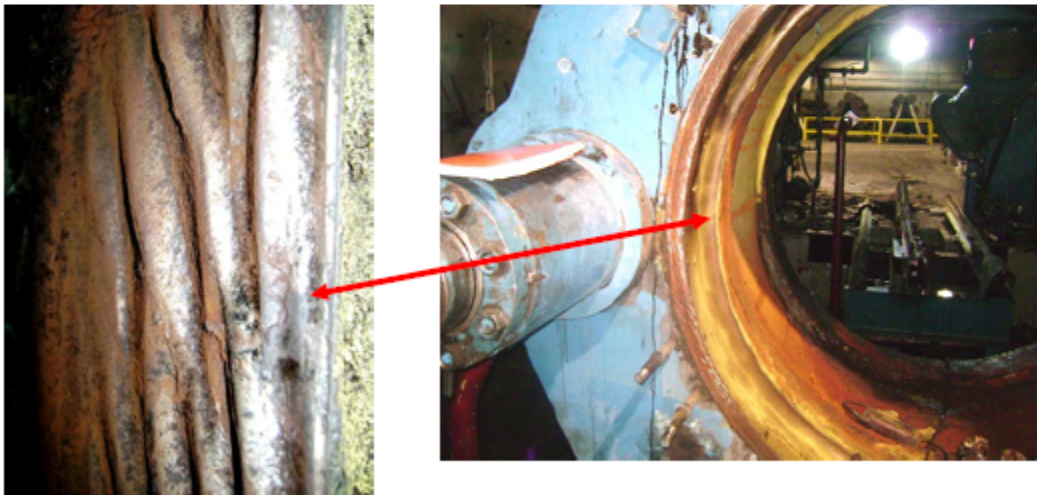


**Figure 13.** Ultrasonic detection of load-bearing flange cracks.

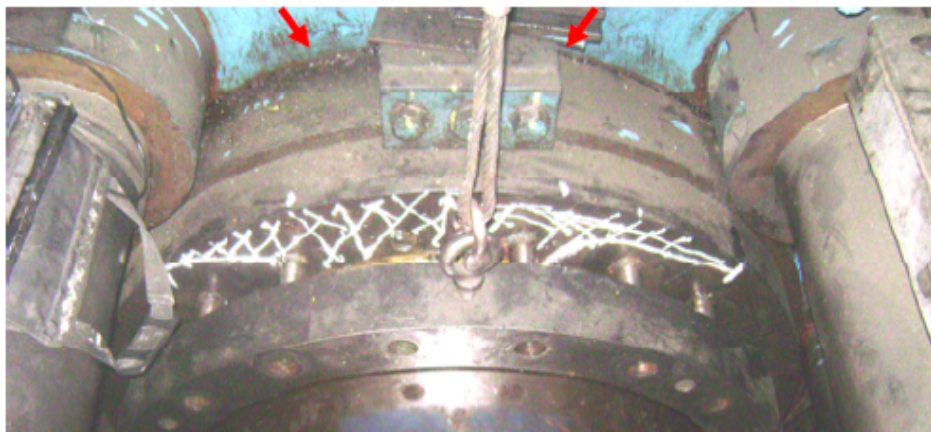


**Figure 14.** This main hydraulic cylinder had fractured at the flange.

Potential of cracking in this area is heightened by press misalignment, and corrosion.



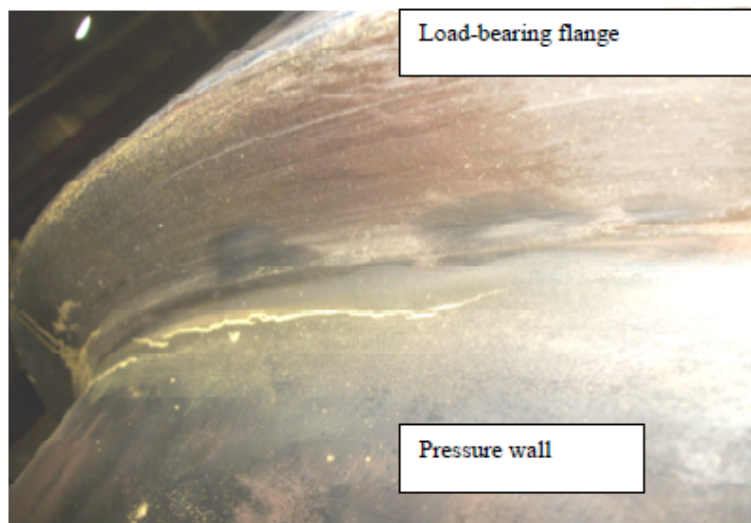
**Figure 15.** The main hydraulic cylinder was being replaced due to a flange crack. Visual examination of the platen revealed this interesting corroded surface of the main cylinder-to-rear platen bearing surface.



**Figures 16a).** A through-wall flange crack is mapped on the front face of the main cylinder flange. The gland packing ring had been removed to provide access for a UT straight beam examination. The crack was repaired, and the main cylinder was returned to service.



**16b)** The picture to the left shows a cracked flange that had been repaired. Holes were drilled through the face of the crack, and threads were tapped beyond the crack. High-strength bolts were added to bind the crack.

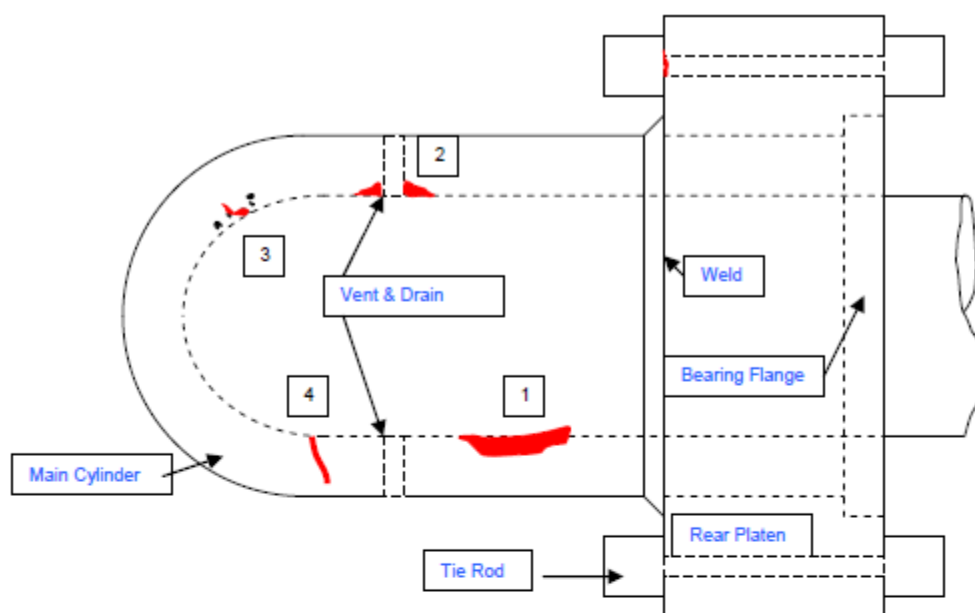


**16c)** The picture above shows an MT indication of a smaller flange crack.

## Main Hydraulic Cylinder Pressure Walls

### Inside Surface Examinations

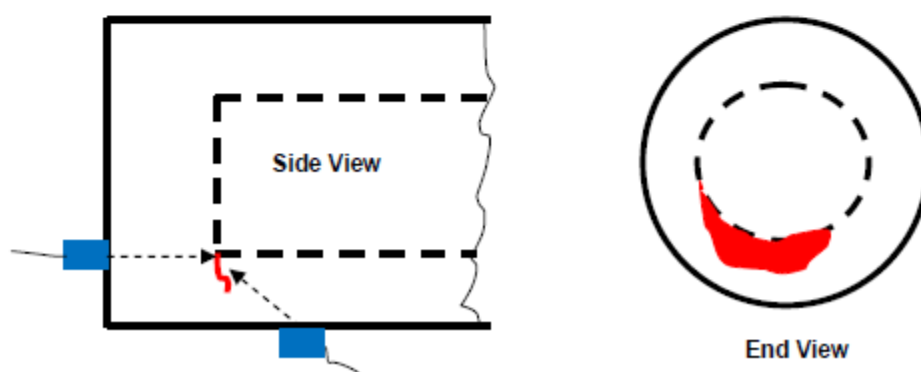
The inside surfaces of the pressure wall are examined with ultrasonic techniques. The examinations are applied from the outer surfaces, directed through the walls, to search for inner surface cracks. On the rare occasions when access to the inside surface is available, the pressure walls should have a direct surface examination visually, and with the Magnetic Particle or Liquid Penetrant methods.



**Figure 17.** Common areas for cracking at the inner surfaces of the main hydraulic cylinder pressure walls.

Cracks in the longitudinal direction at the inside surface (Figure 17, Position 1) can initiate at casting and welding flaws, or other discontinuities open to, or near the surface. These cracks are readily detectable with UT angle beam techniques applied from the outside surface, and can be accurately measured and monitored for growth rates. Similarly-oriented cracks sometimes initiate at the inner radii of vent and drain holes (Figure 17, Position 2).

Cracks in the circumferential direction (Figure 17, Position 4) can also initiate at discontinuities at or near the inside surface. These cracks are readily detectable in their early stages. It has been our experience that cylinders with flat heads are more susceptible to circumferential cracking at the head-to-shell transition.



**Figure 18.** Flat head hydraulic cylinders seem more susceptible to cracking in the circumferential direction at the head-to-shell transition (Figure 16-Position 2).

The resultant voids within the pressure walls act as stress risers. Over time, large cracks can develop. Identifying cracks among casting flaws is difficult. Cracks often develop in a *spider web* pattern. Small cracks grow from one casting flaw to another along paths of least resistance (Figure 19).

These cracks are more identifiable with ultrasonics as the press is operating. Cycling loads cause UT indications of cracks to fluctuate. Indications increase in amplitude as the press is loaded, and diminish when the load is removed (Figure 19).

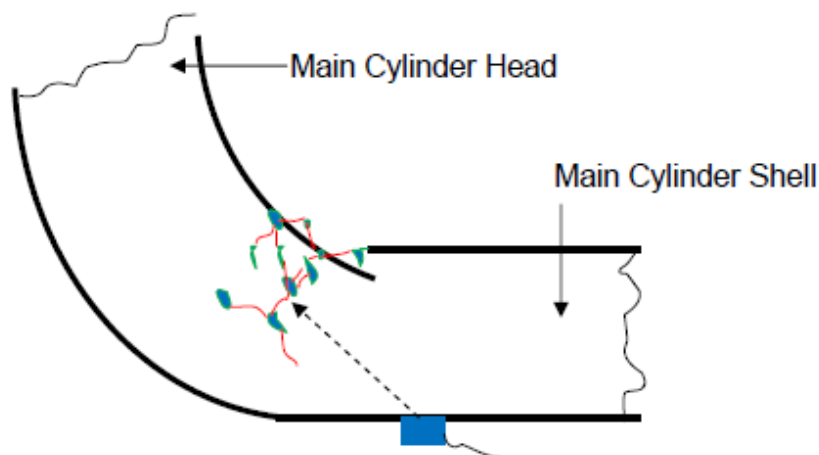


Figure 19. Cracks can develop between casting flaws within cast steel pressure walls.

Most of the inside surfaces of main hydraulic cylinders can be examined with UT techniques applied from the outside surfaces. However, there remain some areas that are not accessible.

It is strongly recommended that if a ram is ever removed from a main cylinder, the complete inner surface of the pressure wall be examined with either the Liquid Penetrant (PT) or Magnetic Particle Testing (MT) method.

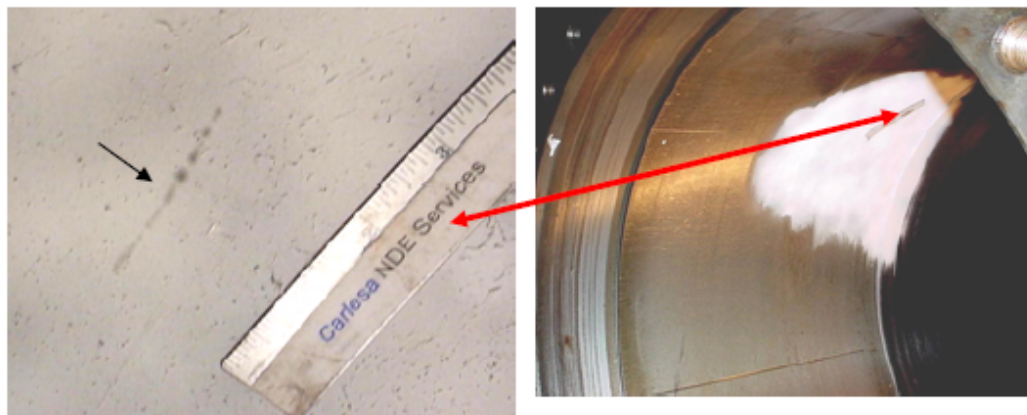


Figure 20. A Liquid Penetrant indication of a crack at the inside surface of a main cylinder pressure wall; the hydraulic oil acts as an excellent indication medium.

Applying comprehensive and periodical examinations of extrusion press main hydraulic cylinders, as well as all major press components, will prevent unexpected failures that could disable a press for long periods of time.

Periodic monitoring will determine crack growth rates, and timely plans can be made to replace or repair components.

**Monitoring the Progress of Fatigue Cracks.** Once cracks have been detected, the frequency of inspection should be increased. It is impossible to specify the frequency for re-inspection, as crack propagation is unpredictable and often proceeds at a slower pace once it exceeds a certain size. Rather it should be based on the severity of the crack and the predicted severity in case of catastrophic failure of the part. We prefer the usual definition:

Total Risk = Severity X Probability of Failure

Considering the consequences of failure, one primary goal of crack monitoring should be to determine when to begin planning to buy a replacement for the part which is cracked.

**Repair vs. Replacement of Failed Components.** Once a significant crack has appeared or a complete break has occurred, the decision must be made whether to repair or replace. The decision is usually complicated by two factors:

- unacceptably long delivery of replacement components
- uncertainty about the life of various repair methods

Most major replacement parts require several months delivery, and no extruder can afford to stop a press for so long. Repairs must be attempted, even if they will not be permanent. (In fact, according to Det Norske Veritas, few repairs to fatigued press parts will be permanent.) So, any repairs must be viewed with the aim of buying enough time to purchase an acceptable replacement.

As to the method of repair, the material in question will determine both the method and the likelihood of success. Parts made of cast iron or low-grade cast steel (main cylinders and platens) are usually the most problematic as long-term repairs on these materials are virtually impossible. If the material of construction of the part is not known, it is recommended to take a small sample of the parent metal from a non-critical location, for analysis to assist in determining the correct welding procedure.

Various eutectic alloy rods are available but require very precise preparation and procedures; for example, UTP () or Castolin Eutectic. Manufacturer's recommendations should be followed carefully in applying these products. Equally critical are the methods for grinding out the cracks, cleaning the surface, and preheating the site before applying the new welds. The preheating and confined spaces make for very difficult working conditions for the welders.

## Procedure for Repairing Cracked Main Cylinder<sup>3</sup>

### Hot Process

- Remove all old weld metal by air-arc torch or grinding. Remove metal 1/3 of wall thickness on each side of the crack (for example, if casting is 6" thick, remove 2".)

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3. This procedure was recommended by Mr. John Hunnicut of UTP, in 1991, and was used to successfully repair a large crack in the cast steel main cylinder of a 1650 press.

- Preheat the cylinder to 500 to 600oF, or as hot as possible, using a torch.
- Use UTP-85FN welding rod and weld a maximum distance of 10 times the diameter of the welding rod. For example, for a rod of 0.125" diameter, maximum length of weld pass will be 1.25". Then stop welding and "peen" the surface.
- When you stop welding each pass, "flip" the end of the rod upwards. That is, turn the tip of the rod up in the air very quickly, instead of just lifting it away from the surface.
- A recommended rod size is 5/32".

## Cold Process

- Remove all old weld metal by air-arc torch or grinding. Remove metal 1/3 of wall thickness on each side of the crack (for example, if casting is 6" thick, remove 2".)
- "Butter" the sides of the opening with UTP-8 rods before welding the crack (that is, cover the sides of the opening with a thin weld coating of UTP-8).
- Some porosity or pin-holes can be expected due to oil in the cast iron. After "buttering" the surface one pass, you should grind away 2/3 of this layer to remove the pin-holes.
- "Butter" the sides of the opening again. There should be no porosity or pin-holes this time.
- Next put one pass in the middle of the crack with UTP-8.
- Change to UTP-86FN; butter the sides again, and weld down into the crack.
- Continue alternating between UTP-86FN and UTP-8 in alternate layers. Always work from the sides down into the crack.
- Always peen after each pass.

Mechanical repairs such as "stitching" have been tried but are generally not successful, even temporarily, due to the high stresses involved and the condition of the parent materials.

As mentioned earlier, purchase of replacement parts should be anticipated as far in advance as possible, through the use of inspection techniques. For many presses, the original manufacturers are no longer in business and detailed drawings are not available. In most cases, re-engineering of the part is also recommended to improve fatigue life and inspectability, as recommended by Det Norske Veritas, so additional time for this step is needed.

Following are notes on recommended repair procedures for specific major press components:

**Main Cylinder.** Weld repairs to the main cylinder, particularly if constructed of cast iron or cast steel, should be considered as short-term at best. With proper attention to procedures as indicated above, short-term (6 months) repairs often may be made. Cracks which arise at drain holes and other stress raisers may

often be welded. However, cracks in the flange or platen area may often be removed by grinding or gouging alone, with no welding necessary. In this case the objective is to stop propagation of the crack by removing it entirely, so it is necessary to dye-check carefully and grind completely to the end of the crack.

**Front Platen.** As with cast cylinders, long lasting welds of cast platens are difficult. Cracks in the tension face of the platen should be removed by hand grinding where possible, and followed with careful inspection to be sure the cracks have been completely removed.

**Tie Rods.** While not permanent, repairs to tie-rods may be an economical alternative in many cases. If tie-rods are removed from service due to fatigue cracks, they may usually be repaired by removing the cracked area to at least 1/8-inch (3 mm) below the bottom of threads; then rewelding sufficiently oversize to permit remachining of the threads. It is important to preheat the tie-rod before welding and to post-heat afterwards for stress relieving. Welding rod material must be chosen to exceed the tensile and yield properties of the tie-rod itself.

**Crosshead.** Cast crossheads pose the same welding problems as the other components previously covered, and similar precautions and limitations should be considered. Weldment crossheads, however, should be excellent candidates for weld repairs. Procedures must include suitable preheat before welding and post-heat afterwards for stress relieving; and welding rod material must be chosen to exceed the tensile and yield properties of the crosshead itself.

**Container Holder.** Older cast container holders are usually unsuited to long-term welding repair. Replacement with a forged weldment is recommended, particularly if the old holder is of the two-piece design. (Replacement also offers a good opportunity to improve container guiding and alignment by eliminating center guides and “X” guide ways. See **Chapter C - Modernizing Older Presses.**)

**Container Guides.** While complete replacement of container holder and guides is often the most economical solution, it is also possible to repair existing guide ways which are not fitted with replaceable surfaces. Various specialty repair firms offer in-place remachining to remove scoring or gouges.

## How Major Components are Designed and Tested

Finite Element Analysis (FEA, also called Finite Element Method or FEM) is now the basic method for design of major press components as demonstrated here.

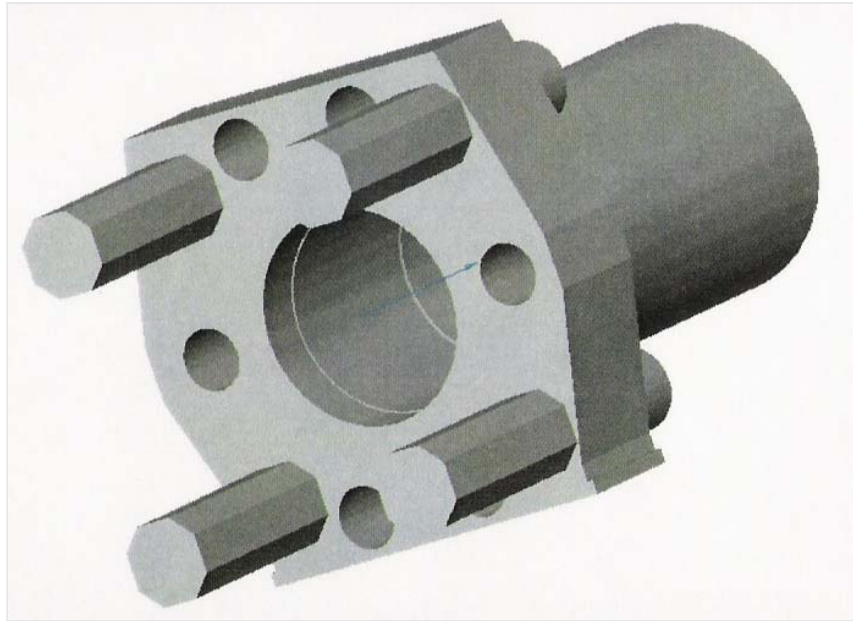


Figure 4-2: Computer Model of Main Cylinder

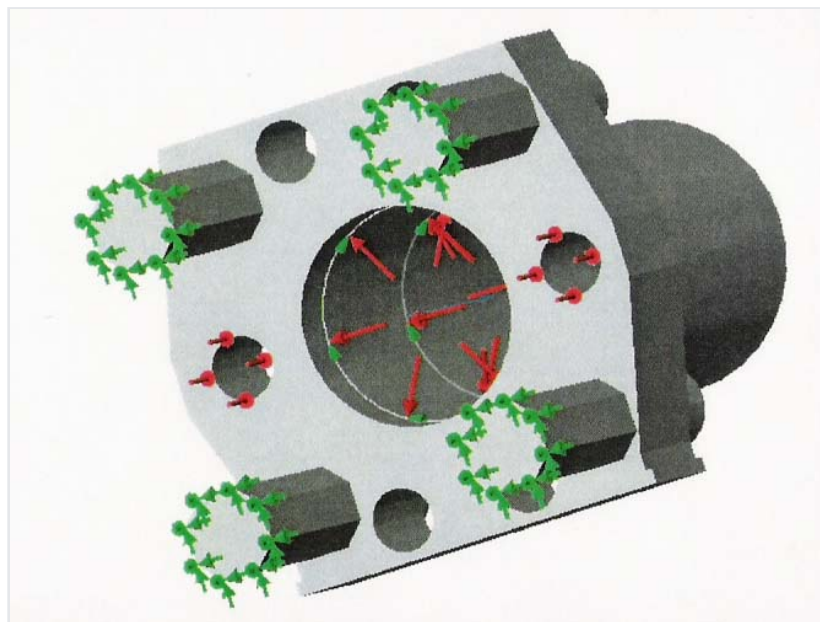


Figure 4-3: Model with Forces Applied

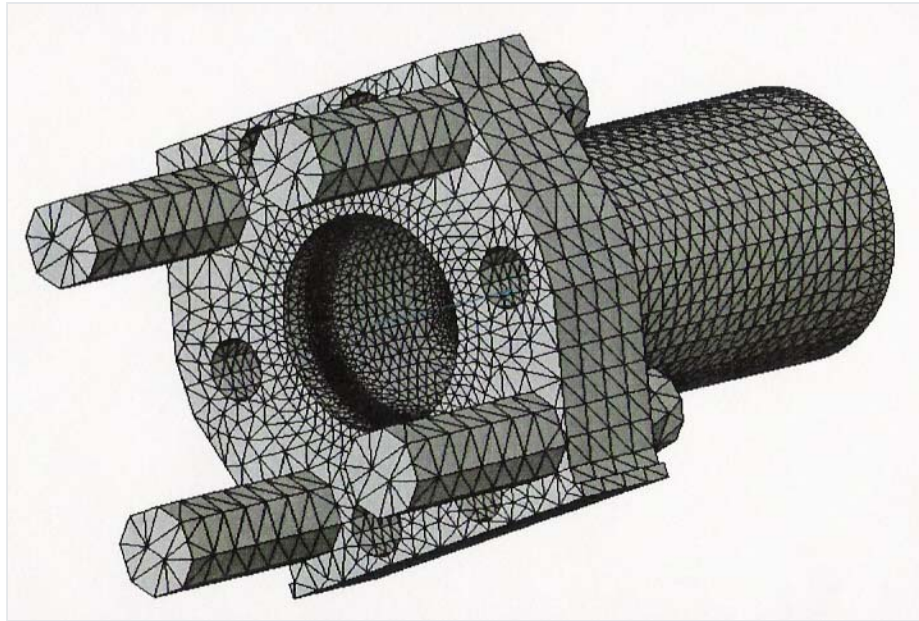


Figure 4-4: FEA Mesh Applied

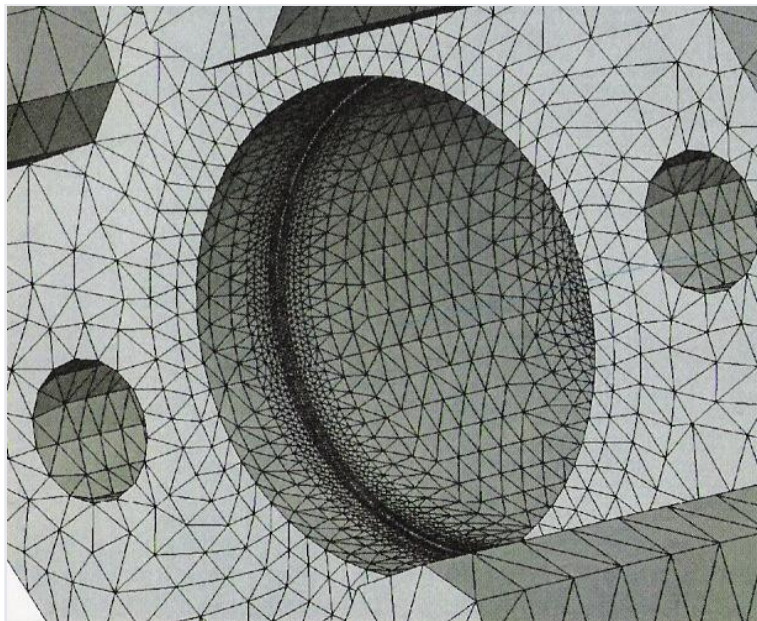


Figure 4-5: FEA Mesh Details

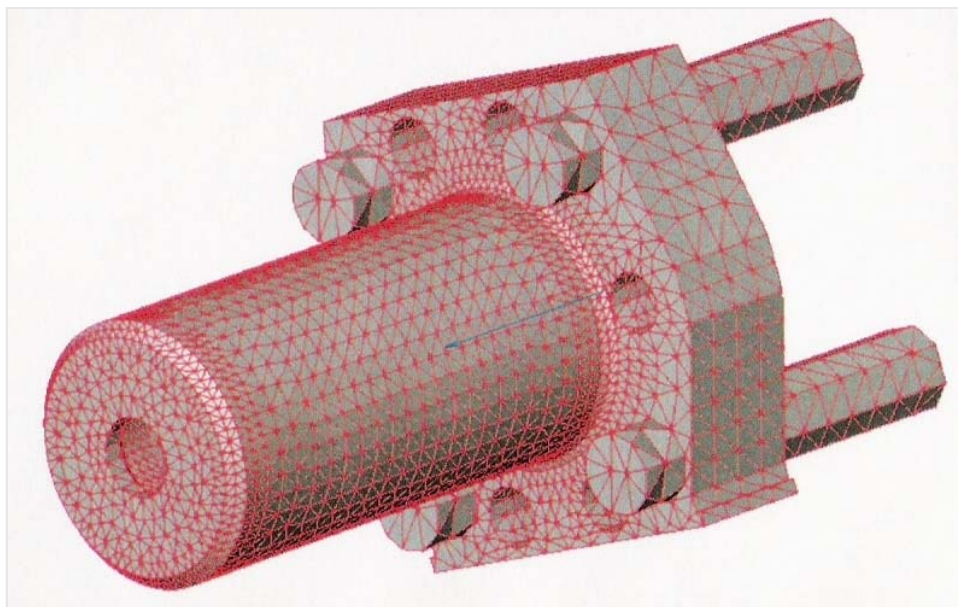


Figure 4-6: FEA Mesh Details

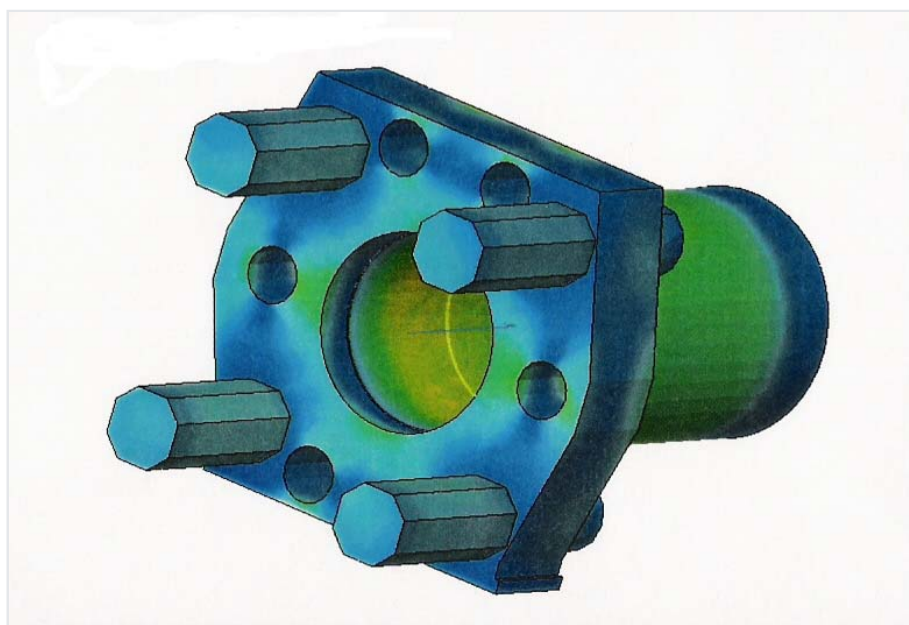


Figure 4-7: Von Mises Result

Illustrations courtesy of Presezzi Extrusion.

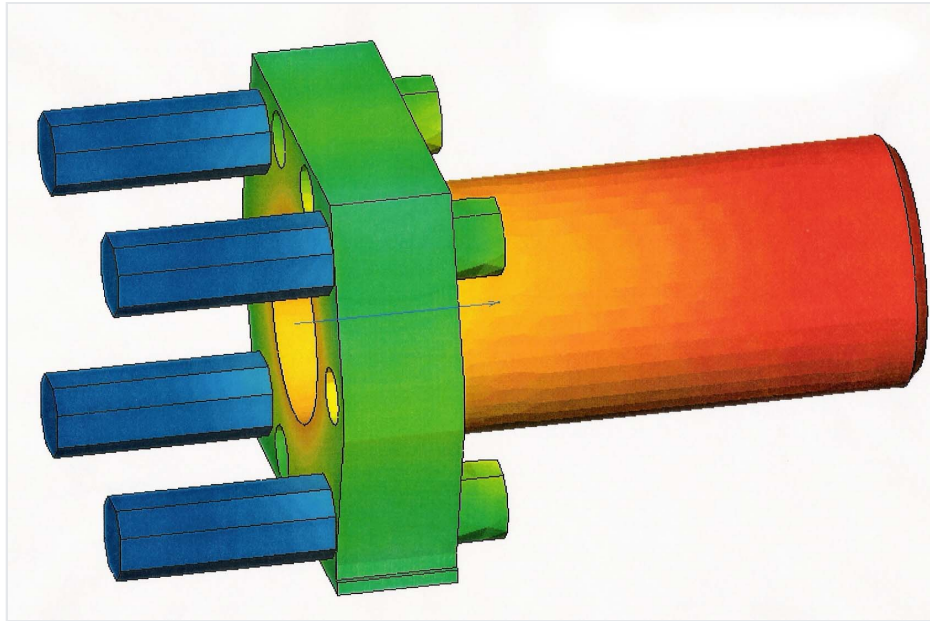


Figure 4-8: FEA Analysis Showing Displacements



Figure 4-9: Ultrasound Test of Main Cylinder



Figure 4-10: Magnetic Particle Test of Main Ram

Illustrations courtesy of Presezzi Extrusion.

### Analysis of Failure of a Container Shifting Cylinder Rod

A paper presented at ET 16<sup>4</sup> reviewed a failure of a container shifting cylinder rod, along with cause, Finite Element Analysis, and recommended redesign of the rod. While the entire paper is recommended reading, analysis of the fracture face is excerpted here to aid field diagnosis of similar problems.

### Fracture Face Analysis

Fractography is the term coined by Carl A. Zapffe in 1944. The purpose of fractography is to analyze the fracture features and to attempt to relate the topography of the fracture surface to the causes and/or basic mechanism of fracture.<sup>5</sup> Through careful examination of the fracture face, many conclusions can be drawn. Different variables affect the look of a fracture from the load types, environmental conditions, and material quality.<sup>6</sup> In the delicate study of the container shifting rod, the fracture face was divided into several sections. Each section seen on Figure 8 was analyzed individually.

The various fracture face features that were identified are as follows:

**Oxide Scale.** This area indicates where the initial crack occurred at an unknown time before the final fracture (this may indicate a weak point in the design of the rod itself).

4. Davidson, Wilson, and Kazanowski, Pawel, "Analysis and Modification of a Prematurely Fractured Container Shifting Rod," Proceedings of 11th International Aluminum Extrusion Technology Seminar, (2016), p.537-554.

5. "Fractography," ASM Metals Handbook, 9th Ed., Vol. 12, ASM International, 1992.

6. Hull, D., "Fractography. Observing, Measuring and Interpreting Fracture Surface Topography," Cambridge University Press, 1999.

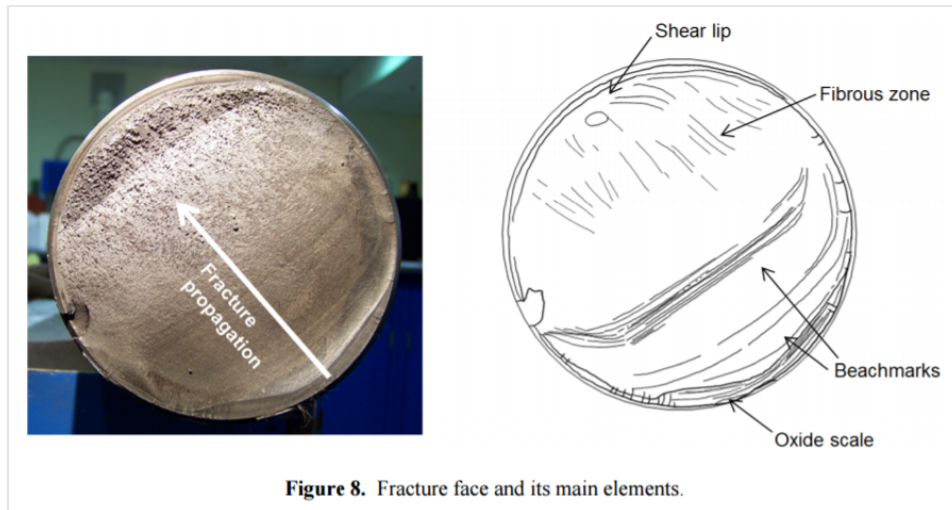
**Stable Crack Growth and Beachmark Zone.** The section illustrates stable growth turning into fatigue cracking, then finally failure. When a crack is growing under an increasing load, it displays a concave or convex appearance, depending on the face of the fracture being analyzed.

**Fibrous Zone.** This large fibrous section is a sign of rapid crack propagation at elevated temperatures.

**Shear Lip.** This was the final overload that fractured very quickly and most likely at an elevated temperature.<sup>2</sup>

The most distinct characteristic of fatigue failures in the field is the beach or clam shell markings on the cyclically grown portion of the fracture. It should be mentioned that similar marks on fractures can be produced under certain conditions by other fracture mechanisms that involve cyclic crack growth without cyclic loading. Also, such marks may not be visible on all materials that fail by fatigue; for example, many cast irons do not develop beach marks. Laboratory fatigue test specimens also do not exhibit beach marks, regardless of the material, unless the test is deliberately controlled to do so, for example, by using load blocks at widely varying loads. Beach marks document the position of the crack front at various arrest points during its growth and can reflect changes in loading that either retard or accentuate crack growth plus the influence of the environment on the fracture face. In a laboratory test conducted at constant cyclic loading in a dry environment, there is no opportunity for beach mark formation.<sup>2</sup>

The origin point for the beachmarks was covered with an oxide film, suggesting exposure to the atmosphere at somewhat elevated temperature. The cracks can be initiated at a wide variety of features, such as scratches, abrupt changes in cross section, tool marks, corrosion pits, inclusions, precipitates, identification marks, and weld configuration defects. In some cases, micro-cracks may be present before loading begins -- for example, grinding cracks, quench cracks, or hot or cold cracks from welding. All these problems increase the likelihood of early failure by fatigue, assuming the presence of alternating stresses of sufficient magnitude. Once that crack is initiated, it can propagate under specific loading conditions like tensile loading and unloading. It is important to note that the distance between beachmarks close to the crack initiation site is quite high, while the distance between the beachmarks close to the fibrous zone is much smaller.

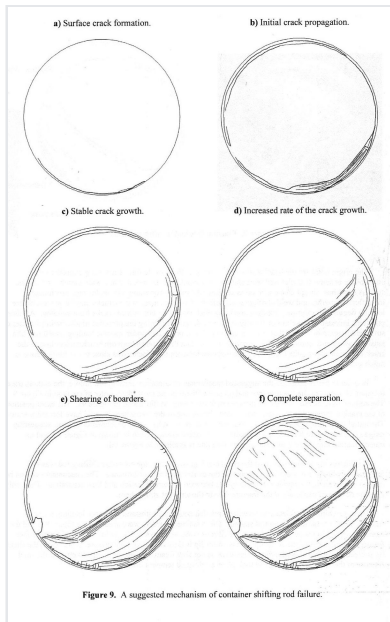


**Figure 8.** Fracture face and its main elements.

In order to better illustrate the suggested mechanism of container shifting rod failure, the authors traced the main elements of the fracture face and presented them in the most likely order of creation in Figure 9. The authors have already discussed surface crack formation, as illustrated in Figure 9a. The exact position of the crack is impossible to determine, so only the outline of the area where it could have formed is shown. The initial crack propagation zone is presented in Figure 9b; it has some beachmarks present, suggesting fatigue fracture due to loading and unloading. The stable crack growth is shown in Figure 9c, and its transformation into crack growth at an increased rate is available in Figure 9d.

It is interesting to note that until the rapid crack growth stage, the container shifting rod was still functioning without any significant impact on the extrusion press performance. The beachmarks cannot be used to approximate the number of press cycles between fracture initiation and final separation. They only indicate periods of exposure of the fracture face to the ambient atmosphere.

Upon reaching the critical cross-section area that could not withstand any more loading, the final fracture of the container shifting rod started. The remaining borders were sheared (see Figure 9e) and the complete separation occurred producing the fibrous zone, as shown in Figure 9f. The final fracture face feature to form is called the shear lip. Large shear lip is created at high temperature; in this case, the shear lip is clearly visible and well defined; however, is not significant enough. It is very likely that the final fracture of the container shifting rod took place at elevated temperature.



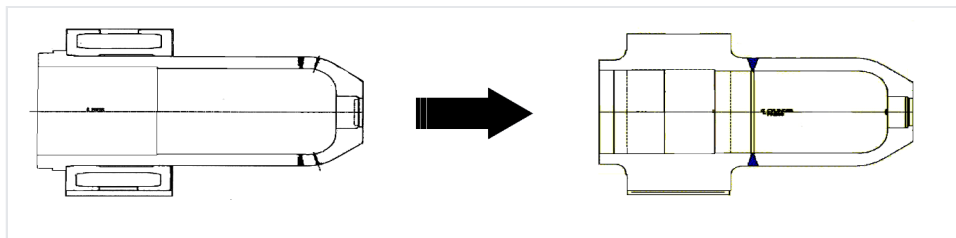
## Improving the Design of Major Press Components

From a presentation by Ben Demar of Butech Bliss at the AEC Press Maintenance Workshop<sup>7</sup>.

When major components must be replaced, or when specifying a new press, improvements to the design may be possible that will improve the life and serviceability of the press.

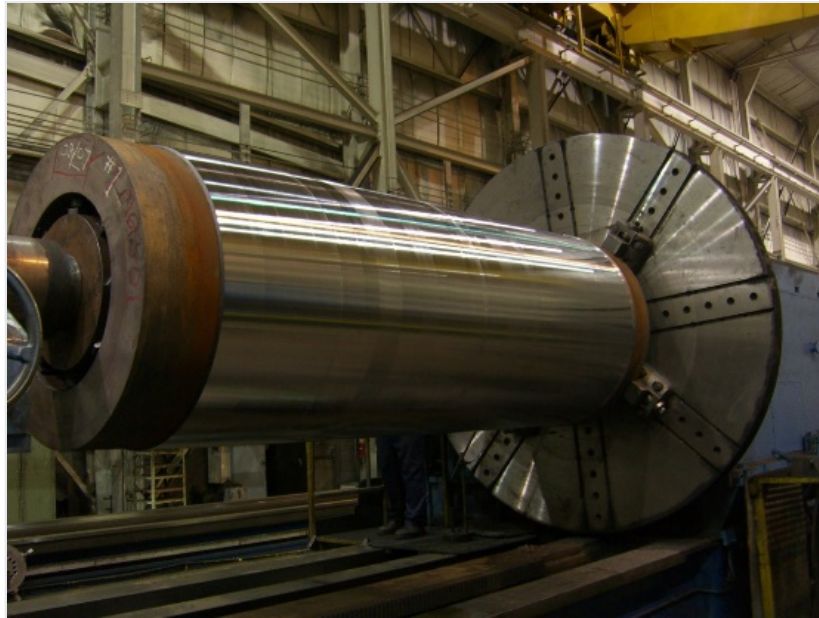
### Main cylinder

- Problems: leaks, weld repairs, parallelism, perpendicularity
- Replace casting or fabrication with re-engineered solid forged cylinder.
- Turn inserted bottle into integrated cylinder platen.

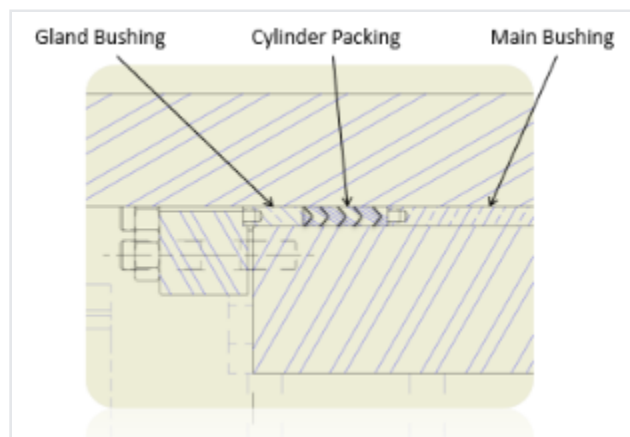


7. Demar, Ben, Understanding Your Press Components from a Maintenance Perspective, presentation at AEC Press Maintenance Workshop, Atlanta, October, 2021.

## Main ram



- Problems: leaks, scoring, cylindricity, trueness
- Replace with re-engineered forged ram; induction harden if/as required.
- Possible alternative: overlay existing ram.
- May also replace cylinder wear components and crosshead wear components.



## Crosshead

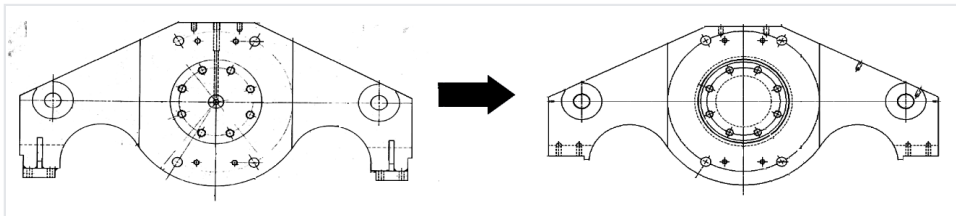
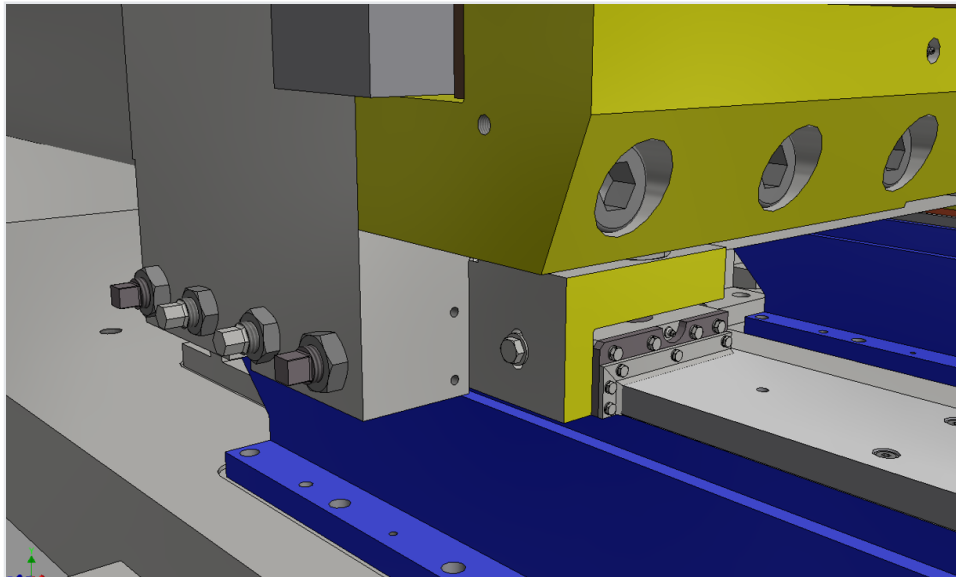
- Problems: loose running, weld repairs, trueness, position (alignment)

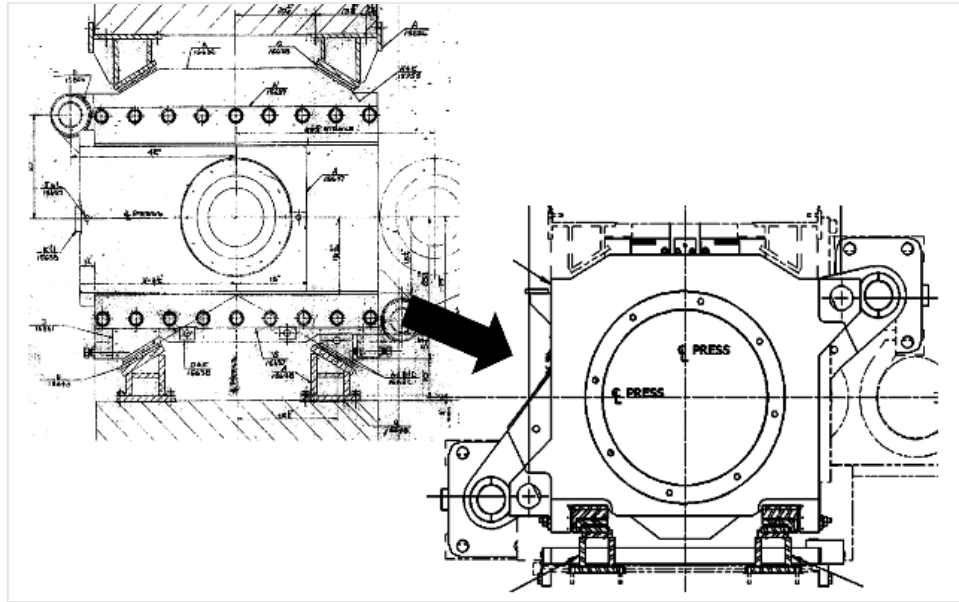
Crosshead structural component:

- Weld repair with OEM or press builder guidance
- Replace with re-engineered solid forged crosshead.

Crosshead replaceable components:

- Vertical & horizontal guide wear plates
- Mandrel crosshead wear plates & bushing
- Convert to flat guide way system





## Container housing



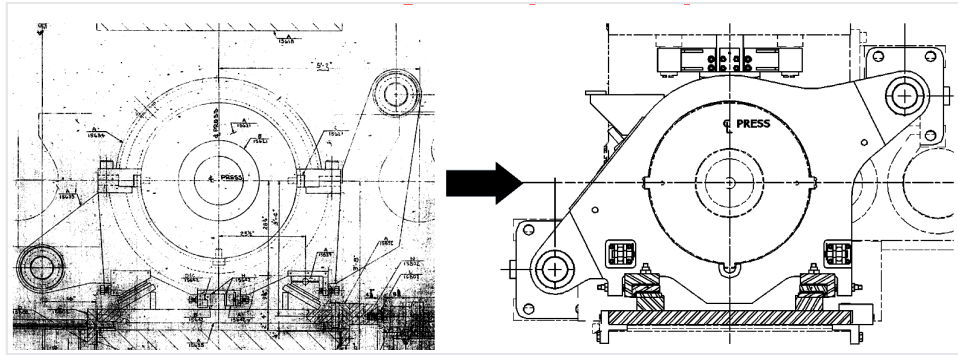
- Problems: loose running, rocking, weld repairs

Container housing structural component:

- Weld repair with OEM or press builder guidance
- Replace with re-engineered fabricated or solid forged component.

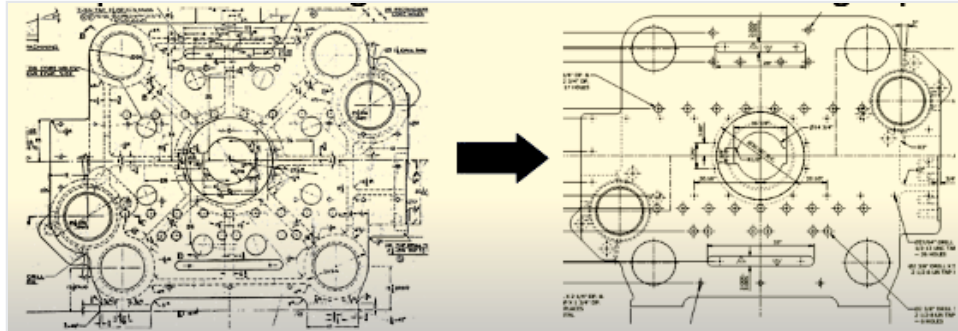
Container housing replaceable components:

- Vertical & horizontal guide wear plates
- Container liner

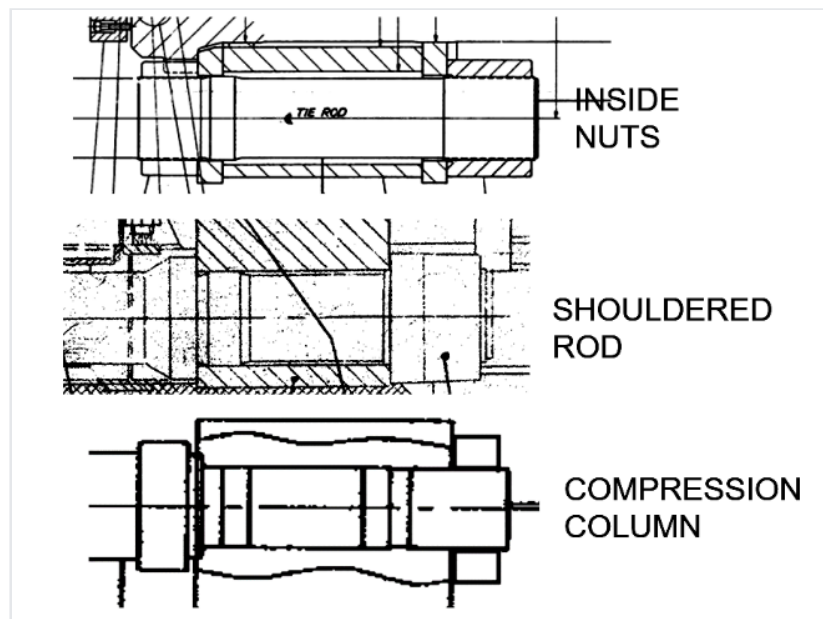


## Platen

- Problems: defects, cracks, weld repairs, parallelism; frame interface, pressure plate counter bore
- Repair with frequent monitoring
- Replace with re-engineered fabricated or solid forged platen



## Frame



- Problems: misalignment, foundation issues, flatness, parallelism; guide ways
- Weld repairs
- Re-grouting

## Tie rods

- Problems: loose nuts, crash effects, wear; loaded vs. unloaded amount of stretch

- Re-assess pre-stress level with OEM or press builder guidance
- Replace and potentially re-engineer thread profile
- Utilize “super nuts” for optimum pre-stress approach

### Return & shift cylinders



Butt shear with knocker

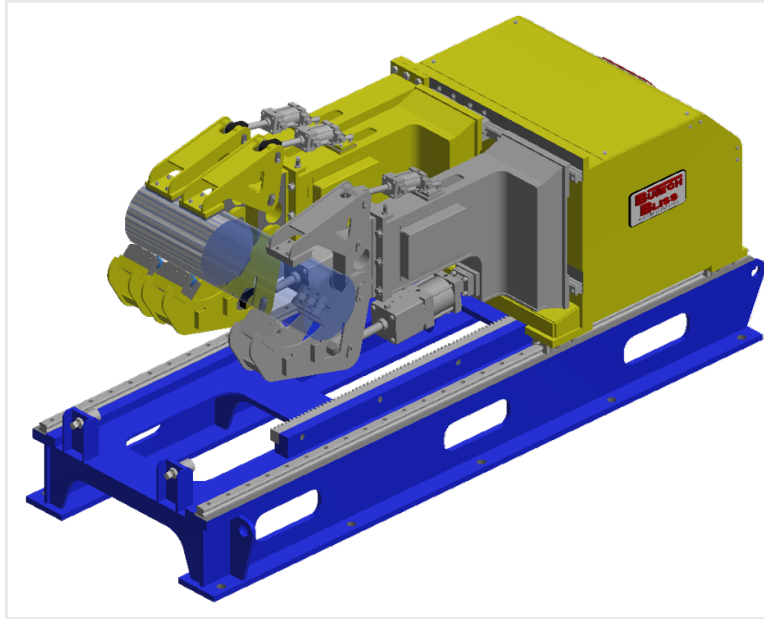
- Keep spares on hand, rebuild or replace when necessary

### Butt shear

- Refurbish cylinder
- Add butt knocker

### Billet loader

- Problems: dead cycle time delays, excessive maintenance, safety concerns
- Upgrade to custom loader (linear/pivoting, hydraulic/electric)



Upgraded Billet Loader

- Knowing your press components, as well as when and how to improve them, is important for a good maintenance program.
- Many tools exist today for both inspection and engineering evaluation, such as Laser Trackers and Finite Element Analysis.
- Don't just replace your worn out or failing components with in-kind replacements – take the opportunity to upgrade them with superior materials and FEA-aided design.

Note: The following paper provides a thorough discussion of the inspection, predictive maintenance, and repair of major press components. It was first presented by the author at the AEC Press Maintenance Seminar, in , , and is reprinted here with permission of the author.

## ADAPTING EXTRUSION PRESSES

### FOR A

## HIGH CYCLE FATIGUE LOAD ENVIRONMENT

by J. O. Nøkleby, Det Norske Veritas

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## 6. SUMMARY -- ADAPTING EXTRUSION PRESSES FOR A HIGH CYCLE FATIGUE LOAD ENVIRONMENT

## 1. BACKGROUND AND HISTORY

Det Norske Veritas, an independent company working with Classification, Certification and Consultancy for various industries, was contacted about extrusion presses for aluminum the first time in 1989, in connection with a failed bolt-type tie-rod on an extrusion press in . The scope of work was to give an independent evaluation on the cause of failure.

Metallurgical investigation of the fracture surface revealed that It was a fatigue failure, initiated in the bottom of the first engaged thread, and developed over a large number of load cycles. No defects or anomalies were revealed regarding thread shape, the surface or the material in the tie-rod, and it was concluded that the cause was a nominal fatigue overload of the material.

Later, other failures, cracks in tie-rods, front platens and cylinders were subjected to failure investigation in similar ways, and it was consistently concluded that the failures were of high cycle fatigue type.

Over the years, the activity of DNV on extrusion presses has grown rapidly. Today, a total number of 44 extrusion presses are more or less regularly inspected by DNV, and preventive maintenance of these extrusion presses is, to a smaller or larger extent, based on advice from DNV. The 44 extrusion presses are located in and , and belong to different owners, although a majority of them belong to one large owner.

As a result of these efforts, DNV has developed a program for preventive maintenance of extrusion presses. Cost/benefit calculations considering the cost of unplanned shut downs along with the cost of inspection, including planned shut down and disassembly for inspection, have revealed that this could reduce the cost incurred by the fatigue problem by about 50%, provided that the program is designed correctly.

Det Norske Veritas, on individual commissions from the different extrusion plants, planned such inspection programs and has carried out the inspections and the investigations of failures. In 1994, we proposed and partly implemented a revised program for preventive maintenance of extrusion presses, based on the experience gained up to that time.

## 2. FATIGUE

An early conclusion from the inspection program and analyses, was that the fatigue problem for extrusion presses was not caused by extremely high loads imposed on them. In fact, the loading on an extrusion press is moderate, with a nominal factor of safety against fatigue failure of 2.0 or even more. Thus, by adequate engineering, it should be no big problem to keep the fatigue threat under control.

However, the business of Aluminum Extrusion was obviously not prepared to tackle this threat. Most of the extrusion presses inspected by DNV are 20 to 25 years old. In the beginning of their lives, thus, extrusion press productivity was much less than in our days, and a fatigue problem, for all practical purposes, hardly existed.

Consequently, designers, along with operators and maintenance personnel, have widely ignored the fatigue problem. This is evidenced through numerous details, like for example:

- Choice of cast steel under poor control, containing inclusions and material defects.
- Lack of detailed stress calculations for transitions, threads and fillets.
- Fillet radii not specified on drawings, and very small in real life.
- Repair welding on castings performed without documentation.

- Tack welding for various purposes performed in uncontrolled manners.

Det Norske Veritas has experienced the similar type of problems in other businesses. The most prominent example was the early days of the Offshore business in the , around 1970. Design solutions, widely based on experience from the , were used for the structures, and resulted in severe fatigue problems. The structures had adequate static strength, and could sustain the hurricanes of the , but failed by fatigue under the more permanent, harsh weather conditions of the . The present fatigue problem for extrusion presses has clear similarities to this case. To solve it, therefore, we will first look into the basics of fatigue, and how other businesses successfully cope with high cycle fatigue problems that can be even more difficult than those of Aluminium Extrusion Presses.

## 2.1 Living in a high cycle fatigue environment

Fatigue failures occur when the fatigue load exceeds the fatigue resistance of the material. In many cases, fatigue failures occur without any kind of nominal overload of the material, i.e. no stresses exceeding the yield limit.

The fatigue loading comprises the local stress level, and the number of times this stress is imposed and relieved. The stress level is the most important parameter, the life (or number of load cycles to failure) is proportional to the stress to the power 3.5 - 5.5. This means that a 10% increase of the stress, leads to a reduction of life by 30 - 40%. Thus, thorough control of the loads and stresses is of essential importance in all engineering to control a fatigue problem. The solution of the problems with the offshore structures in the started with providing better understanding about the wave loads. In fighter aircraft, where fatigue engineering is extremely critical, the service load seen by the individual aircraft, is continuously monitored and used to manage fatigue related maintenance.

The stress in question is the local stress at a spot. The nominal stress is of little importance. Thus, all kinds of local stress raisers, like sharp fillets, scratches, pits or even machining marks or grind marks in the surface must be paid attention, and must be avoided in the most highly stressed areas. The mean stress (which is strongly influenced by welding or uncontrolled heat treatment) is also of significance, and must be controlled. A material's resistance to fatigue loading is primarily dependent on the purity of the material, i.e. its content of inclusions and flaws. The conventional strength of the material is a secondary parameter compared with the presence of flaws. "Aircraft quality" is a well-known expression for metallurgists, and describes a material with extra requirements to purity, absence of flaws, testing, documentation and certification (and cost). These requirements secure that the material's fatigue performance in service is predictable, a vital requirement in fatigue design.

As an extreme opposite can be mentioned cast steel (intended for extrusion press cylinders), with little or no requirements of these types at all (and supplied by the cheapest bidder).

It is not our opinion that the world of aluminium extrusion presses should adapt to the specification level (and cost) of the aviation or offshore industries. But these industries show the direction to go to solve fatigue problems. The key words are control of loads and materials. The challenge to achieve cost efficiency is to go as far in this direction as necessary to get the fatigue problems under control, not more and not less.

## **2.2 Fatigue loading of extrusion presses**

The prime load of an extrusion press is the hydraulic working load, cycling from zero to a nominal pressure and back for every stroke of the press. But this is not the whole truth. No hydraulic regulation system is perfect, and the peak pressure, which occurs only for a very short period of time, can be much higher than the nominal pressure.

Many extrusion press operators now monitor hydraulic peaks as a regular part of extrusion press preventive maintenance. Some of the results have been quite shocking to a fatigue engineer. Crest factors (peak stress to nominal stress) of more than 2 have been monitored, along with very high cycle pressure variations (caused by the pump in absence of adequate dampeners). In some cases, it has been possible to increase the expected fatigue life of an extrusion press by factors up to 3 or more by simple modifications of the hydraulic system, the need for which has been identified through hydraulic peak readings. The present acceptance criterion to crest factor is 1.2. This eliminates the biggest blunders in the operation of the hydraulics, but experience indicates that it is fully possible to reduce the acceptance to 1.1 without unreasonable effects on cost.

This approach copes with peaks occurring regularly, but not peaks occurring incidentally, for example caused by slight sticking in sliding valves of the hydraulics. The main remedy to such problems is cleanliness control of the fluid. A program for such control is started for a few of the extrusion plants where DNV is involved, and is a logical next step for the remaining ones. Maintenance for fluid cleanliness (absence of particles in the hydraulic oil) not only influences the fatigue load, but also the reliability and life of the hydraulic system as such, and an adequately designed program for cleanliness control will clearly be cost efficient.

Another effect of loading is skew loading, resulting in uneven load distribution between tie-rods or false bending moments in front platens and tie-rods due to high friction in the bearing supporting the front platen. In some of the plants, therefore, the loads in the tie-rods are monitored by strain gauges. However, balance influences not only the fatigue load of components, but also the extrusion process, and is paid attention to in most extrusion plants.

## **2.3 Fatigue strength of extrusion press materials**

Fatigue failures have occurred to front platens, tie-rods and cylinders. Failures of front platens and cylinders have consistently occurred in cast materials, where the fatigue cracks have started in material defects of significant magnitude.

The quality of castings has, in general, not complied with requirements of fatigue engineering. In many cases, the amount of flaws and defects in the cast material has been so large, that it has been impossible to inspect the components by ultrasonic testing, and difficult to inspect thoroughly by magnetic particle test. Inspection for cracks is the only way to detect a fatigue failure in due time, and inspectability of materials should be a minimum requirement.

In most cases, the material quality is not documented in any detail, and in connection with trouble shooting and repair it has in many cases been necessary to regenerate material data, based on laboratory measurements and/or field measurements.

It is concluded, that for an extrusion press neither the control of loads nor the control of materials has been adequate for obtaining even a minimum of control of the fatigue problem. For the loads, the problem could be overcome through measurements, but the lack of control and inspectability of existing materials has been a continuous headache in the development of the preventive maintenance program.

### **3. IN-SERVICE INSPECTION, REPAIR AND TROUBLE SHOOTING**

#### **3.1 Development of inspection program**

DNV has developed a preventive maintenance program for extrusion presses with the scope to keep the fatigue problem under control. The program comprises regular inspection for fatigue cracks using Magnetic Particle Inspection (MPI) and Ultrasonic Testing (UT). Fracture mechanics was used to determine the inspection intervals. A crack of length 70 mm and depth 10 mm was assumed to exist in the inner surface of the cylinder, in the most unfortunate direction. The time for this crack to propagate until leak was calculated to 5 years of normal service of the press.

A tradeoff between the technically correct interval (1 or 2 years) and the practically feasible was made, and it was decided to carry out limited inspections from the outside annually, and thorough inspection with opened cylinder every 5 years.

Tie-rods of different designs are comprised among the 44 extrusion presses, but for most of them, annual ultrasonic testing in-service (with tensile load on the rods) was considered the best approach (technically correct from a fracture mechanics evaluation, and practically feasible).

Inspection of the front platens was included in the annual and 5-year surveys. MPI was used annually in accessible areas with the extrusion press assembled, and full inspection was made in the 5-year surveys.

For the sake of cost efficiency, a high degree of "opportunity maintenance" should be applied, i.e. the inspections should be concentrated to periods of limited shut-downs or openings for other reasons than inspection. Decision support programs to optimize the inspection efforts for a given shut-down opportunity are available with DNV.

Along with these inspections, MPI of other components like bolsters, container housings and crossheads are usually included as well, along with hydraulic peak pressure readings, in the annual surveys.

### 3.2 Cast steel cylinders

The inspections have proven the material of many cast steel cylinders to be quite poor with regard to fatigue properties and inspectability. In several cases, internal flaws from the casting process were present to such an extent that ultrasonic testing was not feasible ("total loss of backwall echo"). Also, the outer surface was in many cases too rough to allow adequate contact for the ultrasonic probe, and the rough surface was also quite disturbing for the MPI.

In 32 of the 44 cylinders, cracks have been detected. In 15 cases, the cracks were so large that repair welding was considered necessary, whereas in the remaining cases, grind repair was sufficient. Crack removal by grinding or burning was found to be difficult in some cases, as the cracks apparently were "chased" into the material during the grinding, probably caused by relief of residual stresses. Procedures for "smart" application of thermal compressive stress fields in areas to be repaired were developed, using well-controlled preheating with electrical blankets. Using such measures, it has been possible to solve the problems of cracks that expand during grinding.

In 5 cases, crack surfaces were cut out for metallurgical examinations. The examinations have revealed that the fatigue cracks consistently start from casting flaws. In most cases, these flaws are larger in the middle of the material than near the surface, and consequently a majority of the fatigue failures have initiated inside the material, and not (as assumed in the fracture mechanics model) in the surface. The defects have in most cases been significantly larger than the originally assumed 10x20 mm.

During grinding, it has been noted that new, subsurface flaws can occur. Even such flaws are often filled with hydraulic oil. (Using black light and fluorescent powder during MPI, it is possible to tell the difference between oil filled and dry cracks.) In 4 of the 15 repaired cylinders, new cracks have occurred after repair, often in areas far away from the first repair.

The inspection program for cylinders, thus, has been only partly successful. The reason is that the quality of the cast material was initially over-estimated; there were more and larger defects than assumed. In the worst cases, the material is practically uninspectable, and fatigue cracks initiate in the interior of the material in many locations, where large flaws exist. The crack propagation is promoted by oil pressure in the flaws. The flaws form a more or less continuous pattern over large areas of the cylinder, and openings to the interior surface in the form of pores allow the flaws to be filled with oil.

As a consequence of these findings, the inspection program recommended by DNV has been revised. The new program comprises criteria for rejection of cylinders (replacement or new cylinder), and procedures for estimating the residual life of a cylinder. Presently, these procedures are of qualitative nature, and based on experience. However more consistent, quantitative procedures are in progress. They will be based on extended interpretation of UT signals, and possibly also on trial use of acoustic emission testing to identify growing fatigue cracks below the surface.

### 3.3 Tie-rods

In 24 of the 44 extrusion presses, cracks have been identified in the tie-rods. All the cracks have occurred in the thread region (first thread engaged by the nut), except for one, which started from a tack weld that was, for some undocumented reason, made on the tie-rod.

Crack investigations have revealed that the tie-rods have almost purely tensile load, with only insignificant effects of bending moments. The notch effect is large, so the cracks initiate rapidly, but grow slowly. The service time from when a crack can first be identified by UT to failure can amount to several years, and with annual UT, a wait-and-see attitude has been taken to many of the smaller cracks in tie-rods. In fact, a few of them appear to have stopped, a phenomenon that is also theoretically feasible based on fracture mechanics evaluations, considering the steep stress gradients in a thread. The inspection program has been successful for tie-rods, and has clearly led to avoidance of at least two failures. The program will be continued in unaltered form.

### 3.4 Front platens

Most front platens for the 44 extrusion presses are cast steel, and the material quality in some cases is almost as poor as that for the cylinders. In 25 of the 44 presses, cracks have been found in front platens.

The platens are mainly designed for stiffness, and their nominal stress level is low. Fatigue cracks, therefore, are concentrated at sharp fillets and surface breaking flaws. They are in most cases easily removed by grinding, and only in a few cases has weld repair been called for.

Due to the sharp fillets and the correspondingly steep stress gradients, the crack growth rate is decreasing with increasing crack size. Hence the service time from crack initiation to failure can be several years.

At the center hole, in the contact surface with the die, is another location for crack initiation. Here, cracks can initiate in fretting marks in the contact surface.

Even these cracks, however, seem to have a slow rate of growth, and the 5-year interval between MPI's in this area seems to be adequate.

The inspection program for front platens has been successful, and will be continued in unaltered form.

### 3.5 Experience feed-back and reconsideration of the inspection program

The inspection program has been successful for all components, except for the cylinders. It has demonstrated that all the main components of the extrusion presses are susceptible to fatigue failures after a service time of the order 10 years with the present loading. For replacement components, therefore, improvements are necessary for future successful operation. For cylinders and front platens, the required improvement can be achieved by using higher quality materials, whereas for tie-rods, other kinds of improvements are called for.

Testing of bolsters, container housings, pistons and crossheads has revealed cracks also in these components, and failures have been avoided as the cracks have been detected in due time.

To some extent, the scope of the future inspection program will be to take advantage of the potential remaining lifetime of cracked and/or repaired components. To do this for a typical cast steel cylinder requires an inspection method that can distinguish between growing and non-growing flaws internally in the material -- a material that is practically non-inspectable by UT. Refined ultrasonic testing procedures, or possibly acoustic emission (AE) may have the potential to satisfy this requirement, and trials of AE for extrusion press cylinders will most likely be started in 1995.

## **4. FAILED COMPONENTS -- REPAIR OR REPLACE?**

### **4.1 Cast steel cylinders**

The majority of cylinders in the extrusion presses inspected by DNV are made of cast steel, and were delivered in the 1970's. Fatigue cracks, originating from casting defects, with various depths from a few millimeters up to full penetration through the wall, have been successfully repaired by welding.

This requires a thoroughly elaborated welding procedure, adapted to the parent material in question, and comprising well-controlled heat treatment using electrical blankets before and after welding, and careful execution of the welding itself. With high constraint, high residual stresses in the material and unhomogeneous parent material, it is by no means an easy operation, and there are several examples of unsuccessful weld repairs from the past. However, it is our experience that these problems have now to some extent been overcome, and failed cast steel cylinders are, in general, repairable by welding.

But the repaired cylinder can still be full of flaws outside the repaired area. Possibly, fatigue crack growth is in progress from several such flaws. Most cast cylinders have an amount of material defects making them, for practical purposes, uninspectable by ultrasonic testing. Thus, even after repair, the cylinder will be susceptible to further fatigue failures, and there are many examples that leak number 2 occurs within 1 or 2 years from the first one.

Thus, when a cylinder has failed by leak, and other fatigue cracks in progress have been identified, it is usually considered that the cylinder has reached the end of its fatigue life, and replacement with a forged cylinder is the only option.

In a few cases, cylinders made of cast iron have been found. It is DNV's opinion that cast iron is not suited for extrusion press cylinders under modern, tough service, and we consistently advise replacement of cast iron cylinders.

In other cases, weld repairs with the use of stainless electrodes have been found. Experience is that such areas develop new fatigue cracks after a short time of service. Repair procedures using stainless welds are therefore generally not recommended.

## 4.2 Tie-rods

A threaded tie rod is a highly stressed component, with fatigue performance strictly linked to very fine geometrical (and metallurgical) tolerances in the thread area.

Thus, we see no method for permanent repair of a threaded tie-rod with a large fatigue crack in it.

The crack growth in a tie-rod, however, is quite slow when the crack exceeds a certain size, and the remaining life of a tie-rod where a crack has been identified can be many years. It can, in some cases, be stretched further by turning the nuts in order to displace the point of maximum loading to outside the cracked area. The crack growth can be followed by ultrasonic testing, and by choosing the interval for such testing adequately, it is not considered risky to run a tie-rod with a known crack in it for some time.

When interpreting the ultrasonic signals, it is important to know the material used in the tie-rod. Different materials are in use, from normalized mild steels to high strength quenched and tempered steels, and their response to fatigue crack growth, as well as their response to ultrasonic testing, can be quite different.

## 4.3 Front platens

Front platens have been repair welded several times. Whenever such welding is done with adequate quality assurance measures (like those described for cylinders), repair welding has been successful, and it is concluded that front platens made of cast steel can readily be repaired by welding if they develop fatigue cracks.

Only in cases where very poor material quality has been identified in front platens, has replacement been found necessary.

# 5. REQUIREMENTS FOR REPLACEMENT COMPONENTS

## 5.1 General

It is fully documented that a majority of the failures experienced with extrusion presses in recent years are of the fatigue type, and have occurred because the designs and materials of major extrusion press components have not been adequate for modern press operation. Replacement components, therefore, can not be made by relying on past experience of suppliers, or designs of yesterday. Novel approaches, with much increased emphasis on fatigue properties, must be found. It is a major challenge for the buyers to secure that this innovation is achieved simultaneously with the best price for the supply. The answer is detailed specifications, to be used as basis for the bidders. DNV has developed such specifications for supply of castings, forgings, welded connections and tie-rods, with reference to recognized quality standards well known to suppliers in and respectively.

The specifications are based on material specification principles used in the offshore business, but are adapted to the special requirements (regarding cost as well as quality) of aluminium extrusion presses.

In many cases DNV, through its international network of offices, follows up the production and testing of the materials and components in different countries on behalf of the client.

## 5.2 Cylinders

Standards for castings, meeting the requirements that need to be set for fatigue performance of cylinders, are available. Theoretically, therefore, it is possible to continue using cast cylinders.

However, it has been found in practice that it is difficult or impossible to make foundries commit themselves to meet such strict standards for large castings like a cylinder.

In practice, therefore, the choice for new cylinders has usually been forgings, with one or two circumferential welds. Close control of the weldments has been found necessary to secure that casting defects are not replaced with weld defects, but this is no big problem using modern welding methods, and modern Quality Control measures for welds.

Only in a very few cases, practical or commercial constraints have made it difficult to order forged cylinders in one piece, and the choice has been cylinders assembled by welding. Thorough strength analyses and fatigue calculations have shown that this is only possible by going to the very limits of what is technically possible in terms of fatigue performance for welded connections. Comprehensive quality assurance measures are called for, and even then the result has been designs that must be characterized as marginal with regard to fatigue performance.

## 5.3 Tie-rods

Threaded tie-rods with conventional nuts have a stress concentration factor of the order 10 in the bottom of the first engaged thread. This basic fact leads to the conclusion that most threaded tie-rods are critical, or close to critical, with respect to fatigue. The high fraction of cracked tie-rods found during the inspections reflect this basic fact, and leads to the conclusion that even for tie-rods improvements with regard to fatigue performance are called for.

The easiest solution is probably a redesign of the nuts, giving a reduced stiffness in way of the first engaged thread (so called tie-nuts). There are different practical solutions here, but some of them are hard to apply in practice due to limitations of available space.

Further, the geometrical tolerances of the thread (shape, pitch and surface roughness) are important for the fatigue performance of the connection, and should be kept within pre-defined limits.

Techniques for local improvement of fatigue strength of the thread bottom, like cold rolling or shot peening, have been discussed, but have so far not been used in tie-rods supplied where DNV has been involved. Lack of documentation of final properties, particularly in terms of tolerances, is one important factor that causes reluctance to apply such measures.

For tie-rods of other designs than threads, the stress concentration factor is smaller, and the fatigue problem can be kept under control by more simple QA measures.

## 5.4 Front platens

Front platens are, in general, designed for stiffness and thus moderately stressed. Material specifications for new front platens are therefore not so strict as those for cylinders. Material requirements should secure a minimum of weldability in the case of repair welding, inspectability of the material by use of UT, absence of large flaws, and avoidance of sharp notches.

## 6.0 SUMMARY -- ADAPTING EXTRUSION PRESSES FOR A HIGH CYCLE FATIGUE LOAD ENVIRONMENT

The paper describes the activities of DNV to adapt extrusion press design and maintenance to the high cycle fatigue load environment that arises under modern, high performance operation of the presses.

The efforts are twofold:

- To take maximum advantage of available remaining life of existing extrusion presses, without unacceptable risks for sudden fatigue failures.
- To specify replacement components that will sustain the service requirements of today and tomorrow.

A systematic inspection program, presently covering 44 extrusion presses, is carried out, and the experience is systematically fed back into programs for condition evaluation, predictive maintenance and specifications for replacement components.

Adequate fatigue performance of major extrusion press components requires the use of designs and materials that are superior to what was formerly used. However, the solutions are well known from other fields of engineering, like offshore structure or the automotive industry.

by:

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Editor's Note: At ET 2004, Rick Colden and Adam Cramlet presented the following paper describing a temporary repair and eventual replacement for a main cylinder on a 1675 Tons Wean press. The following condensed version of their paper describes both temporary and permanent repairs and the creative methods used to shorten the cylinder replacement time. Refer to the original paper<sup>8</sup> for the complete story. We are grateful to them for sharing their experience and ideas with the Extrusion ustry.

## **Catastrophic Failure: A 48 Hour Remedy**

### **The Problem: A Crack in the Main Cylinder**

Even with a predictive maintenance program that incorporated annual ultrasonic testing, a crack initiated and propagated through the ductile iron bell housing on one of Extrusions' 7" presses. Initially a 1972 Wean 1675-ton press, it was converted to 1900-ton capacity in 1995. This crack initiated from the inside of the bell housing at the drain plug location, which made it extremely difficult to detect with ultrasound. Immediately after detection of the leak, a forged bell housing was ordered from Lake Park Tool, with an estimated 12 to 16 week lead-time for a complete forged and machined housing. However, because of the urgency, Lake Park Tool was able to finish the housing in just 10 weeks. Fortunately, the drawing verification and quoting process was already completed, so no time was sacrificed in the design or purchasing process. A new housing was not kept on hand due to its high cost and the belief that the ultrasound testing would give enough forewarning to order a new one and have a minimal amount of downtime.

To slow the rate of growth of the crack until the main cylinder could be replaced, the maximum operating pressure of the extrusion press was reduced from 3400 psi to 2500 psi. Press operators were advised to run billets at elevated temperatures to facilitate running the same extrusions with a 25% loss in tonnage. This resulted in decreased production because the higher billet temperatures required slower extrusion speeds to sustain acceptable exit temperatures. A second extrusion press with spare capacity was available, but not enough to entirely cover for the press with the cracked housing. As a last resort, work could be sent to other extruders.

A rudimentary measurement of the crack growth was accomplished by measuring the volume of oil lost over a set period of time. From these measurements, it became obvious that the crack was growing at a rapid rate and needed to be dealt with promptly. As the crack grew, supplemental hydraulic cooling was required because of the heat created from the oil flowing through the crack.

### **Temporary Repair:**

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8. Colden, Rick, and Cramlet, Adam, "Catastrophic Failure: A 48 Hour Remedy," Proceedings of 8th International Aluminum Extrusion Technology Seminar, (2004).

There was only one choice in the repair method due to the size of the crack, its location, and the time required for the repair. After the size of the crack was found with magna-flux testing, a plug and patch system was designed as a temporary fix. The size of the crack through the thickness of the housing was estimated in order to size the plug. The plug was turned and machined out of 11" round 4140 steel stock, and the main cylinder housing was machined from the inside to match the profile of the plug. The housing was machined with a portable boring tool. The plug was then machined to match the milled out portion of the housing. This plug locked itself in place with a radial keyway and key, which was machined into the plug. O-rings were also installed in the plug to help seal it. The plug was threaded on one end and a 2" thick bent washer was held in place by the nut and welding around the outside perimeter of the washer. **Permanent**

### Repair:

Figure 4-12: Main ram saddle with 4 jack bolts, side guiding cam followers and machine rollers.

Figure 4-13: Rear truck with top clamp bar (left) and front truck with top clamp (right). Both trucks are outfitted with machine rollers and cam follower assemblies. Each truck has jack bolts controlling vertical and horizontal adjustment.

Figure 4-14: Main cylinder housing cam follower plates.

Figure 4-15: 9.5" diameter 1" thick wall steel tube with tapered fitting (above) and main cylinder housing with cam follower plates (below).

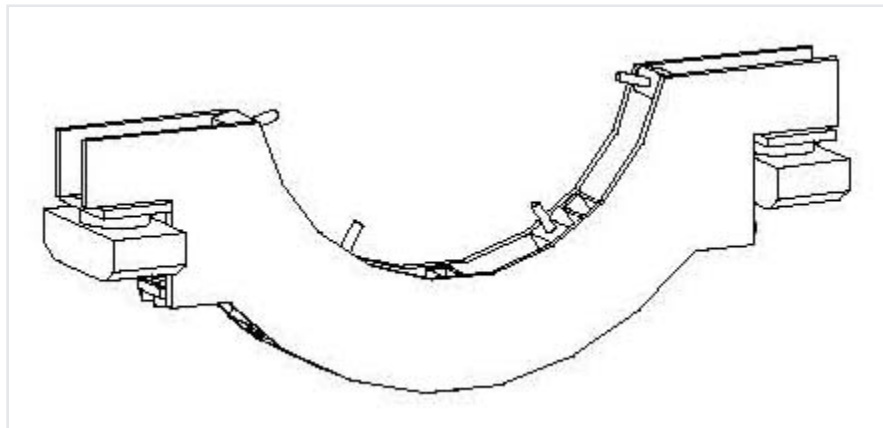


Figure 4-11: Main cylinder housing plug and patch assembly.

Completing the change-out in the minimum time with minimum loss of production required careful planning and scheduling, including development of innovative rigging tools. Proposals from outside contractors for changing out the cylinder housing indicated a changeover time of two weeks. It quickly became apparent that different rigging methods were needed for this project. Blocking, jacking and shifting the large pieces were the major time consumers in the proposal. That method of rigging simply would not be rapid enough, so it was deemed necessary to design custom rigging devices.

## TOOL DESIGN

All of the rigging devices were designed with speed and safety in mind.

- For the repair of the housing, the ram needed to be removed and reinserted. To accomplish this, two saddles with jack bolts, for adjustment, were built. These saddles supported the ram from the underside and rode on the ways of the press with machine rollers. Adjustable lateral guides were built into the saddles to keep the ram from losing its alignment.
- To remove the main cylinder housing from the press, the pre-fill valve would need to be shifted sideways with a miniature bridge crane mounted to the underside of the oil reservoir.
- A rod, truck and cam follower design was implemented for removing the main cylinder housing. It was determined that a long, thick walled steel tube slightly under the diameter of the opening in the back of the housing where the pre-fill valve bolts on to the main cylinder housing would support the entire housing. The steel tube was fitted on one end with a tapered fitting that would insert into the front platen pressure ring later on in the removal process. The steel tube was also fitted with a locking device securing it to the platen to prevent accidental movement. The steel tube was supported on one end by an adjustable truck and on the other end by another adjustable truck and the platen of the press. The trucks had machine rollers at their base to allow them to move along with the housing. The housing itself would ride on the steel tube through a system of bolt-on cam follower assemblies that attached to both ends of the housing.
- In order to remove the main cylinder housing and the main ram, one of the top tie rods needed to be moved out of the way. This was done by sliding it partially out the front platen and supporting it with a simple stand.

## DRAWING VERIFICATION

Drawings of all components that were to be replaced were cross-checked with the original drawings and compared to its field application to make sure that there were no interferences if changes were made from the original design, or were dry fitted at the press. All drawings were prepared and verified to be correct before the components were ordered. As the components arrived they were measured for dimensional accuracy or inspection data was required from the supplier to assure that the parts were built to print. The drawings were also used to verify weights to properly plan for tool design and rigging.

## SCHEDULING

**For both the repair and replacement sequence for the bell housing, scheduling was a critical issue for everyone from the customers to press crew personnel. Customer service maintained close contact with the customers to keep them informed of potential delayed or missed orders. Maintenance crews were requested to expand their hours by up to 50% when necessary. To temporarily supplement the maintenance crews during the change-out, outside millwrights were also hired. Press personnel were scheduled to remain at the press area and supplement the maintenance crews when less technical tasks needed to be done.**

## REPLACEMENT COMPONENTS

All moderate to low cost wear items, including o-rings, fittings, hoses and seals, were planned on being replaced. After removing and cleaning old components, they were fitted with these new items. All tapped holes had a tap run through and all fasteners were inspected. Unless there was proof any of these items had been replaced recently, it was decided to replace them.

## COMPONENT ORGANIZATION

In this project, the importance of labeling and organizing components was not an oversight. This was a critical step that affected the speed at which the press was reassembled. Containers were labeled for containing small components such as nuts, bolts and fittings. Organizing in this manner made it extremely easy to clean and prepare these small parts. Anything that couldn't fit in a bucket would be labeled with marker or a tag and digitally photographed in its original position on the press to avoid any confusion at the time of reassembly. All documents, photographs, etc. were posted in the immediate press area for easy clarification. This concept would prove especially helpful with electrical components, conduit, hydraulic piping and hydraulic fittings.

## TOOL ORGANIZATION

Tool carts were set up for each of the smaller jobs mentioned earlier. These tool carts contained all the tools needed for removing and installing the components. This guaranteed that tools would be kept together, which meant no searching for missing tools. A small amount of tools were purchased just to make sure each cart had a complete set of tools. Also, extra tools were purchased as back up in case the original tool failed without having one readily available locally.

## JOB ORGANIZATION

The organizational mindset for setting up jobs was similar to a pit stop at an automobile race-track. In order to maximize efficiency and manpower, multiple tasks or jobs were organized to run simultaneously. This would allow maintenance personnel to run these smaller tasks in parallel by using press personnel, millwrights, or both to lend support. Millwrights were to be recruited for their expertise with handling large pieces of equipment and rigging, but they still would operate under the supervision of maintenance. The list generated of changeover and repair jobs included removal and installation of: container, container housing and stem, tie rod, pre-fill valve, hydraulic lines, electrical lines and conduit, ram and bell housing. A Gantt chart was developed and posted outlining all of the specific tasks, person responsible and time-line for each operation.

## RIGGING

The main ram and main cylinder housing tooling was specially designed to speed up and make safer certain parts of the rigging, but the usefulness of that tooling ended at moving and locating the main ram and main cylinder housing into a position where it could be rigged with another piece of equipment. A portable gantry crane was provided by the millwright company to pick the main ram and main cylinder housing out from the press frame. To insert the rod into the housing for its removal, an overhead crane and forklift were used. An oversized forklift (again supplied by the millwright company) was used to transport the ram and housing to and from the gantry crane and into and out of the plant.

## IMPLEMENTATION

### MAIN CYLINDER HOUSING REMOVAL

To speed up the process, a few days before the press was shut down, all components not needed for operation of the press were removed, such as the hydraulic reservoir mezzanine, sound curtains, etc. Hydraulic and electrical power were retained for removal of the container, stem, container housing and to loosen the necessary tie rod nuts.

Figure 4-16: After end of ram is blocked up and crosshead is removed, saddles are placed under it.

Figure 4-17: Tie rod is shifted and ram is in position to be removed with gantry crane.

Once the ram was run out partially and supported, the cross head was extracted and the saddles put into position. The shear blade had to be chained up to keep it from closing off the platen hole. The main shutoff valve for the oil reservoir to the pre-fill valve was closed and the hydraulic lines, electrical lines and conduit were removed. At the same time, the temporary plug and patch were removed and the bell housing cleaned and checked for high spots that might have caused problems extracting it from the rear platen. These high spots were then ground flush.

Once those tasks were completed, two teams were formed. The first team attached the crane to shift the oil pre-fill valve and the second shifted the tie rod out of the front platen. A come-a-long then pulled the ram out into a position so that it could be picked out by the gantry crane. After the ram was removed from the press frame, the tooling system for main cylinder removal was put in place. Both cam follower fixtures were bolted to the front and back of the housing and trucks positioned in the rear and the front of the housing. The rod was then inserted through the back of the cylinder and fastened to the front platen of the press. A clamp was also placed on the rear of the rod as a safety measure. The jack bolts on both the front and rear truck were raised to align the housing vertically and horizontally for extraction. Come-a-long power again was used to extract the housing. Due to the stress levels that the steel tube could handle, great care was taken in the positioning of the trucks with respect to the housing. Both trucks were kept as close to the housing as possible at all times. Once the housing was shifted to a location under the gantry crane, the load was removed from the pole and the pole extracted from the housing. The old housing was then removed from the press frame with a gantry crane and from the site with a large forklift.

## MAIN CYLINDER HOUSING INSTALLATION

Figure 4-18: Pre-fill valve is shifted and main cylinder housing removal tooling is positioned.

Figure 4-19: Main cylinder housing is shifted into position to be slung by gantry crane to allow for rod removal.

The installation of the new housing and reassembly of the press was the exact reverse of the removal process with few differences. A power washer was used to clean the entire press (especially the rear platen) before reassembly. The area where the housing fits into the rear platen was also closely inspected for any damage that may have occurred during the extraction process. Any burrs or galling that may have occurred during the extraction process were ground and buffed out. Certain new components replaced old or worn out items. The housing itself was packed with ice to make it fit into the platen easier. Fasteners and the contact area between the housing and the platen were coated with anti-seize lubricant and all the nuts torqued to manufacturer specification.

## RESULTS

On Wednesday evening the extrusion press disassembly began, and by Thursday , the press was ready to receive the new bell housing. A few hours were lost because the new housing arrived at on Thursday, and a few problems were encountered getting the housing off of the trailer due to its great mass. The housing was packed with ice and cooled for a couple of hours before reassembly began. Friday night at the press was extruding at full pressure. Throughout the duration of this project, the cost of meetings, engineering, tooling fabrication, and millwrights didn't exceed \$25,000. By computing with hourly press rates alone, approximately \$200,000 was saved because of the speed at which the old housing was extracted and the new one installed as compared to the quoted lead-time.

With the aid of merely two outside hired resources, the new housing was installed and the press was running at full power inside of 48 total hours from the time it was shut down. This was made possible because of tremendous organization from the planning team, inventive tooling design, and great effort from shop personnel.

## **CONCLUSION and RECOMMENDATIONS**

In conclusion, a predictive maintenance program must be able to catch fatigue cracks before they begin to grow at an exponential rate; otherwise its existence gives a false sense of security and could do more harm than good. A good predictive maintenance program would include removal of the ram and inspection of the inside of the housing as well as the outside. It is highly likely that this would have resulted in catching the crack much earlier in its growth. Early detection would have allowed for unhurried ordering of a replacement and a smaller plug to temporarily repair the housing if necessary. Though removing the ram itself is a daunting task, with specialized tooling this feat can be achieved in a reasonable amount of time and in a safe manner.

All facilities should have up to date drawings and suppliers picked for large, built to order items such as tie rods, platens and main cylinders. From the date of order, if a company has the resources, then the planning, tooling design and tooling build should be able to take place before the new components arrive. However, if an extruder relies heavily on an old piece of equipment and cannot afford any downtime, then it is recommended that spares be purchased, tooling built and a plan generated in case of a catastrophic failure. Due to lost pressure it was extremely difficult to loosen the tie rod nuts to move it. It would be sensible to keep an auxiliary tie rod at your disposal in the case that pressure is lost quickly and the tie rod needs to be cut off to extract the ram and housing.

## **Additional Recommendations for Successful Component Replacement**

To purchase a replacement part, contact:

- Original press builder (if still in business)
- Other press suppliers
- Major component suppliers

To get multiple bids you will need detailed drawings and specs

- Buy drawings?
- Have them made?

Important to specify:

- Forged (not cast)
- Forging tested & certified before machining

- Design by FEM
- No sharp radius – polished out, no tool marks
- Ultrasound and MPI after machining

Track fabrication progress with visits to supplier's plant:

- Is it on schedule?
- Are dimensions correct?
- Observe tests.

**NO SURPRISES !!!!!**