THE REVIEW OF PHYSICAL CHEMISTRY OF JAPAN, VOL. 37, No. 2, 1967

HIGH PRESSURE APPARATUS: RAM-IN-TIE-BAR MULTIANVIL PRESSES

By H. TRACY HALL

A multiaxial press is described in which pressing members such as anvils, punches, pistons, and dies are brought together along a plurality of geometrical axes by a contracting framework. These pressing members impinge upon an appropriate cell to generate pressure. The cell and/or its contents may be heated or cooled while under pressure by external or internal means. The preferred embodiment of this apparatus can be envisioned by substituting pull-type hydraulic rams for the fixed, rigid tie bars of a conventional multianvil press such as a tetrahedral press. Thus the "Ram-In-Tie-Bar" (RITB) press has variable length tie bars. The base mounted push-type ram of the conventional press is replaced by a fixed post to which an anvil is attached. The new press has a number of advantages over conventional multianvil presses which are equipped with an anvil guide:

(1) The Ram-In-Tie-Bars serve as an integral anvil guide, thus eliminating the need for the usual guide. This greatly increases the working space in the anvil region and facilitates the use of X-ray diffraction devices and other equipment in conjunction with the press.

(2) The total ram tonnage required to obtain the same anvil load is reduced. Thus total RITB tonnage for a tetrahedral system is only 0.6123 that of a standard (rigid tie means design) tet press and for a cubic system is only 0.7071 times the total ram tonnage of a standard cubic press.

(3) Larger presses of RITB design can be built than can be built in standard design.

(4) RITB presses are less expensive than conventional types, especially in the larger sizes.

(5) The use of external heating and cooling is greatly facilitated in the new press.

Introduction

The prototype multianvil high pressure apparatus, a tetrahedral press, was described in 1958[1]. In multianvil presses the moving pressure inducing element usually consists of a relatively incompressible body that has a generally prismatic-shaped working end. This is called an anvil. Anvils are normally constructed of cemented tungsten carbide, the most resistant material to breakage by compression currently available. Simple tetrahedral anvils are shown in Fig. 1. The anvils depicted, which have triangular faces E and sloping shoulders F on the working end, will fit perfectly together when moved inwardly along the tetrahedral axes A, B, C, and D. When so fitted, they completely enclose a regular tetrahedral void. The anvils of a multianvil press are thrust together by mechanical, hydraulic, or other means.

(*Received January 3, 1968*)

1) H. T. Hall, *Rev. Sci. Instr.*, **29**, 267 (1958), See also U. S. Patent No. 2,918,699, Dec. 29, 1959

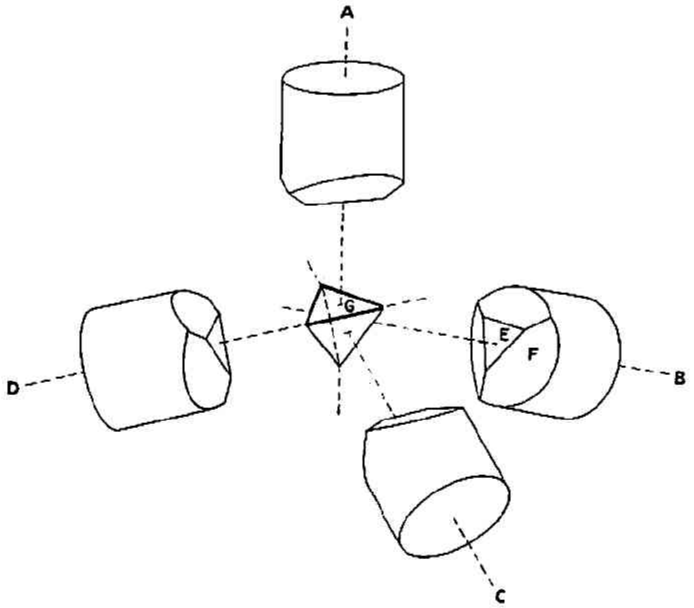

Fig. 1 Tetrahedral anvils, axes, and cell

To generate pressure the anvils impinge (in a symmetrical manner along the tetrahedral axes) upon a tetrahedral cell G. The triangular faces of the tetrahedral cell G are larger in area than the corresponding faces of the anvils. As the anvil faces push against the cell faces, edges of the "oversize cell" are extruded into the spaces between parallel sloping shoulders F. This automatically forms a "gasket". With continued advance of the anvils, the gasket compresses, yields, flows, extrudes and achieves a balance between frictional, pressure, and other forces to seal and provide for pressure built-up within the tetrahedral cell. Nominal pressures of 100,000 atmospheres (1,500,000 psi) are readily achieved within the tetrahedral cell in actual devices.

The cell is usually constructed of a fine-grained solid substance with proper frictional, compressible, thermal, electrical and chemical characteristics. An oft-used cell material is the hydrous aluminum silicate mineral pyrophyllite, which is known in the trade as grade A lava or wonderstone. The tetrahedral cell is cut apart and/or drilled to provide cavities for the sample, electrical heaters, thermocouples, and other bodies. The dismembered cell is then cemented back together to enclose the sample and other desired element. A resistance furnace within the cell makes it possible to readily achieve a 2000°C temperature simultaneously with the 100,000 atmosphere pressure. In some instances it is desirable to utilize preformed gaskets along the six edges of the tetrahedral cell rather than have the gaskets automatically formed.

Anvil modifications

Although the simple tetrahedral anvils pictured in Fig. 1 are the most commonly used, it is sometimes desirable to depart from the "perfect or exact fit geometry" of the prismatic end. Thus edges and/or surfaces may be rounded (concavely or convexly), the angle of the sloping shoulders with

The Review of Physical Chemistry of Japan Vol. 37 (1967)

respect to the face may be varied or may be sloped at one angle for a distance and then at another angle for an additional distance, or the shoulder form may be curved or contoured. The same is true for the form of the face. These modifications give anvils that fit imperfectly together with respect to the manner in which the simple anvils fit. Explained in other words, the shoulders F do not contact each other over their entire surfaces when the anvils are brought together without a cell being present. Also, the "void" formed by the anvils in contact may only approximate the shape of a tetrahedron. In addition, the void may not be totally enclosed by the contacting anvils. Modified anvils, by achieving a more delicate balance of the forces and other factors involved in pressure generation, have made it possible to obtain pressures considerably beyond 100,000 atmospheres. Regular tetrahedral cells may be used with modified anvils, although it is often preferable to use cells conforming to the shape of the anvil ends. Molded, inorganic and filled plastic cells conforming to the exact shape of the working ends of the anvils have been extensively used in the Brigham Young University High Pressure Laboratory. Such cells have been used with and without molded, preformed gaskets.

Higher order presses

A hexahedral or cubic anvil system is shown in Fig. 2. In a cubic press, six anvils with square faces are thrust together to impinge upon a cube-shaped cell which again may or may not have preformed gaskets along its edges. Other features and modifications discussed above relating to tetrahedral presses apply equally well to cubic presses. Obviously the multianvil press concept includes octahedral presses, prismatic presses and higher order geometrical configurations.

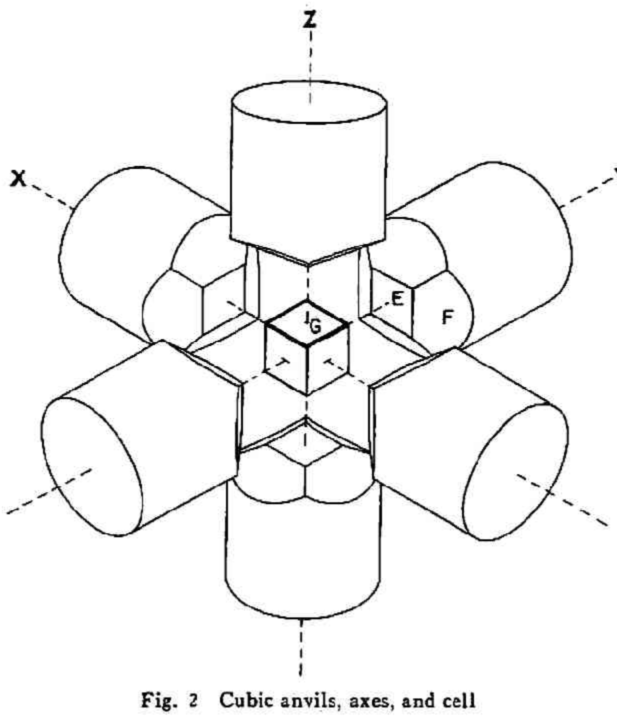

Fig. 2 Cubic anvils, axes, and cell

The Review of Physical Chemistry of Japan Vol. 37 (1967)

It is interesting to note that a cubic press is a triaxial device (the anvils move along three independent axes to generate the pressure), whereas a tetrahedral press is tetraxial; *i. e.*, the anvils move along four independent axes. Considering the active and reactive forces acting on a small, semi-fluid (under pressure) solid sample centered in a pyrophyllite tetrahedral or cubic cell, the sample "sees" a more "hydrostatic" pressure in a tetrahedral system than it does in a cubic.

Anvil guides-space problems

A major improvement in multianvil presses came in 1962 with the invention of the anvil guide[2]. This device synchronizes and coordinates the motion of the anvils so that they advance uniformly and simultaneously toward the center of the press. It also eliminates anvil alignment problems that were present in early presses. The anvil guide, however, ordinarily occupies considerable space in the vicinity of the anvils and reduces the working room there. This presents problems when certain equipment (such as an X-ray diffractometer, an external heating furnace, or a cooling system) is used in conjunction with an anvil press, because the guide mechanism is in the way. Note that an anvil guide mechanism was not used in the hydraulically actuated X-ray diffraction press described by Barnett and Hall[3]. Rather, each hydraulic ram was individually valved for ingress and egress of hydraulic oil, and anvil position was monitored by means of dial indicator gages. Coordination of anvil motion was manually controlled by the operator as was done in the early tetrahedral presses. The improved multianvil press described below provides new means for synchronizing and coordinating anvil motion and provides for open space in the vicinity of the anvils. Also, the new press, which is called a "Ram-In-Tie-Bar" (RITB) press, possesses some additional advantages in its own right.

Ram-In-Tie-Bar Presses

A drawing of a hydraulic RITB tetrahedral (tet) press is shown in Fig. 3. An actual press would be much more compact, but this press has been "stretched-out" along its tet axes for illustrative purposes. In a conventional tie bar press, anvil motion is usually provided by rams or jacks mounted on bases which are held in fixed position by tie bars. In a tet press, there would be four push-type rams* with an anvil mounted on the moving end of each ram. The rams, of course, would advance the anvils toward the center of a tetrahedron defined by the tie bar axes. The tie bars, together with the bases, provide a rigid framework to support the thrust of the rams. A cross section of a conventional hydraulically-actuated tet press is shown in Fig. 4. A RITB tet press, in contrast to a conventional tet press, utilizes six pull-type rams or jacks. Each ram or jack replaces one fixed tie bar in the conventional press (see Fig. 5) giving, in effect, a tie bar of variable length. The rams that are

2) H. T. Hall, *Rev. Sci. Instr.*, **33**, 1278 (1962), See also U. S. Patent No. 3,182,353, May 11, 1965

3) J. D. Barnett and H. T. Hall, *ibid.*, **35**, 175 (1964), See also U. S. Patent No. 3,249,753, May 3,1966

* Most rams "pull" as well as "push". However, when a ram's primary function is to push (usually by extending its length) it is called a push ram. Its major work is done during the push cycle. During the pull cycle, secondary work (usually only retraction of the working components) is performed. Likewise, the primary function of a pull ram is to move its main work load during a pull cycle (usually by contraction or shortening of the ram).

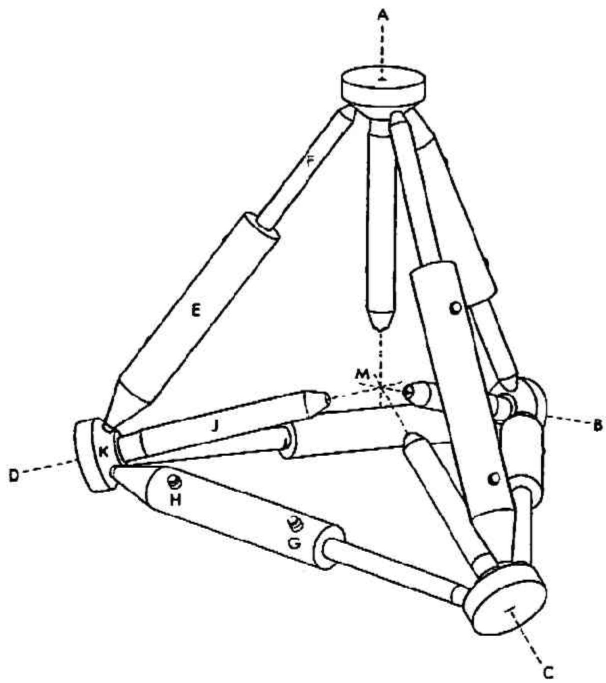

Fig. 3 A hydraulically powered Ram-In-Tie-Bar tetrahedral press
The lines A, B, C, D which intersect at M are the tetrahedral axes of the press along which the anvils move. The triangular faced tetrahedral anvils are mounted on the free ends of the anvil posts J. These posts are fastened to the bases K which are caused to move in and out along the tetrahedral axes by the pull rams E. Hydraulic oil, under pressure, enters the ram at G, causing retraction of the rod F into the hydraulic cylinder. This action causes the anvils to move synchronously toward the center of the press M. Hydraulic oil entering at H expands the press causing the anvils to move away from M.

normally mounted on the bases are replaced with fixed posts to which the anvils are attached. The anvils are thrust together by the "pull" of the "in-tie-bar" rams rather than by the "push" of the rams in conventional design. When hydraulically actuated pull-type rams are used in RITB presses, they are designed according to principles previously given[4]. Hydraulic oil is simultaneously admitted to all rams to either advance or retract them.

Integral anvil guide

A most interesting feature of a RITB press is that the rams in the tie bars serve as an integral anvil guide system. The mechanical constraints on the entire assemblage of Ram-In-Tie-Bars and bases are such that all the bases (and hence all the anvils) must move simultaneously, equally, and in complete coordination toward the center of the press. As can readily be seen from the figures, this new arrangement provides much more open space in the vicinity of the anvils.

4) H. T. Hall, *Rev. Sci. Instr.*, **37**, 568 (1966)

The Review of Physical Chemistry of Japan Vol. 37 (1967)

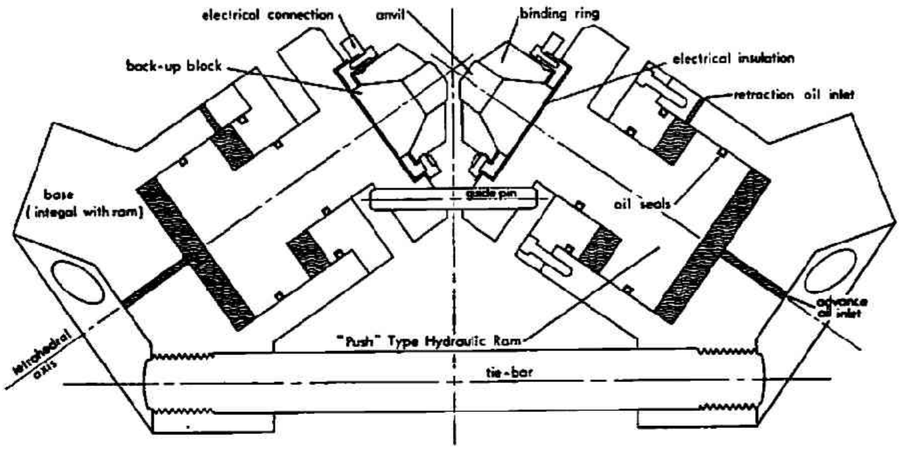

Fig. 4 Plane section through axes of two hydraulic rams of conventional tetrahedral press

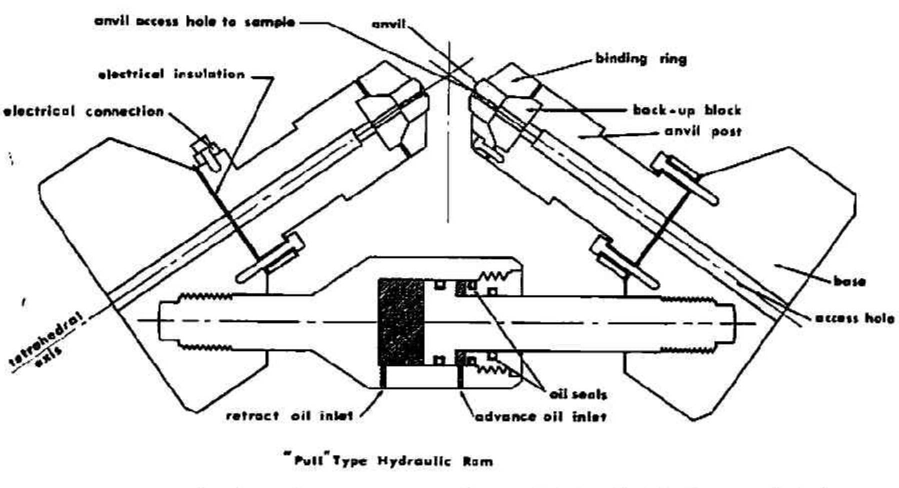

Fig. 5 Plane section through axes of two anvil posts in Ram-In-Tie-Bar tetrahedral press actuated by a pull-type hydraulic ram

External heating and cooling advantages

In multianvil presses it is usually desirable to electrically isolate the anvils from each other in order that the anvil faces may serve as electrical connectors to resistance heating elements or other devices located within the pressure cell. This has usually been accomplished by placing insulation as shown in Fig. 4. In the RITB arrangement, it is desirable to place the electrical insulation at the bottom of the anvil post. This moves the insulation away from the anvil region where unit compressive stresses are high and places it in a location where the loading per unit area upon the relatively soft plastic laminates used for electrical insulation can be reduced. With this accomplished, all components in the anvil region can be constructed of metal. This makes it possible to heat the anvils (and consequently the enclosed pressure cell and its contents) by an external furnace without burning or overheating the plastic electrical insulation. It is desirable to construct the anvil post of a low thermal conductivity material, such as stainless steel, to provide a favorable situation for either heating or cooling the anvils by external means. In the latter instance, liquid nitrogen or other coolant can be circulated around the anvils to perform experiments at low temperatures. The size and mass of an anvil post is much less, of course, than that of a hydraulic ram. Consequently, the anvil region can more easily be heated or cooled without excessive transfer of heat. Also, the post can more readily be constructed of a low thermal conductivity material than can an entire ram. In addition, the anvil post can be relatively long and slender, thus providing a long heat path. A push-type ram must, of necessity, be rather bulky and constitutes a large heat sink.

Base diameter reductions

Another advantage of RITB presses is the fact that the bases (K of Fig. 3) can be considerably reduced in diameter and thickness over that required in a conventional press where a push-type ram is mounted on the base. The push-type ram, being much larger in diameter than the post of Fig. 3, requires a correspondingly larger diameter base. This requires the tie bar ends to be fastened to the base at a greater distance from the base center line. Thus a thicker base must be used to give the same support. The decreased size of the bases in the RITB press allows the threaded ends of the tie bars (or the ends of other style fasteners) to be moved in closer to the center line of the base/anvil axes.

Access hole to sample

The cross sectional diagram of a RITB tet press of Fig. 5 shows an "access hole" extending from the bottom of the base through the anvil post, the back up block, and the anvil, on into the sample. Similar access holes have been described before in connection with providing means for entrance of an X-ray beam to the sample in a conventional tetrahedral press[3]. However, because of the fact that a hydraulic ram was mounted on the base, the ram piston had to be hollowed and access from outside was through a section of the piston perpendicular to the ram axis followed by a section along the ram axis. In other words, the path from the outside traversed a right angle bend before reaching the sample. Additional complications arose because of the limited hollowed-out space available in the piston of the ram and also from the fact that the piston moved with respect to a stationary cylinder. In contrast to this, note the simple, uncomplicated, "line of sight" access hole in a RITB. In the conventional X-ray diffraction tet press the X-ray tube had to be mounted directly inside a moving ram in a crowded, inconvenient, complicated manner. In a RITB press X-ray tubes or other appliances can be mounted on the bottom of a base, outside the press, where there is plenty of room for arranging the various parts.

Higher order RITB presses

The RITB concept is not limited to tetrahedral presses, but can be applied equally well to hexahedral (cubic), octahedral and prismatic presses, and to any type of regular or irregular, symmetrical or asymmetrical multianvil type device.

Tonnage, stroke, size, and cost comparisons

Some comparisons between RITB and conventional designs for tet and cubic presses are of interest. Consider, for example, a standard 200 ton tet press. This is a common research size instrument in which each of the four push-type rams is of 200 ton capacity. In a RITB tet press of the same capacity, the six pull-type rams would each be of 82 ton size. When the six RITB rams are each exerting an 82 ton pull on the connecting bases, geometry dictates that the thrust along the anvil post axes equals 200 tons (the same as the thrust of the 200 ton push rams located on equivalent axes in a conventional design). The total ram tonnage for such a press would be $6\times 82=492$ tons compared to $4\times 200=800$ tons for a conventional tet press.

Now consider a 200 ton cubic press. The standard design would use six push-type rams of 200 tons each (total tonnage is $6\times 200=1200$). The new design uses 12 each, 71 ton pull-type rams (total tonnage is $12\times 71=852$) to accomplish the same purpose.

While the total ram tonnage in the new RITB designs is smaller than in conventional designs, the ram stroke (the motion required of the ram to move the anvils unit distance) is proportionately larger. For tet presses the RITB design requires 1.632 times the ram stroke of the conventional design. Individual RITB pull rams are 0.4082 the capacity of the conventional push-type rams, and total ram tonnage is only 0.6123 times that of the conventional design. The corresponding factors for cubic presses are 1.414 times the ram stroke, 0.3535 times the individual ram tonnage, and 0.7071 times the total ram tonnage.

The increase in ram stroke required in RITB presses is readily obtained at insignificant additional cost and increase in size because the anvil motion required in all multianvil presses is relatively small. The decrease in total ram tonnage in RITB presses, on the other hand, results in significant reductions in size, weight, and cost. This particularly comes to light when very large presses are considered. For example, if it were desired to construct a conventional cubic press of 10,000 tons capacity (the size of each individual ram) it would be difficult to find a manufacturer who could produce rams of this size for this use. The pull-type rams in an equivalent capacity RITB unit, however, would be only 3550 tons in size. These could be fabricated much more readily than the 10,000 ton push-type rams. In standard machine shop practice there is a region in which the cost of fabricating larger and larger pieces of equipment rises steeply. Under such circumstances, if it is possible to redesign a machine so that it contains a larger number of smaller parts, a considerable reduction in cost can be achieved. The RITB press offers this particular advantage over the more conventional multianvil high pressure devices. In addition, because of machine tool size limitations, it offers the possibility of constructing larger presses than would be possible with conventional design.

Sure guide

While the idealized mechanical constraints imposed by the RITB geometry insure perfect alignment and motion of the anvils, practical considerations of machining tolerances, clearances of sliding fits in the rams, and friction may allow too much anvil position error for very exacting experimental situations. When it is needed, a simple, geometrically redundant mechanism is of value in improving the precision of anvil motion in RITB devices. It is called the "sure-guide" and is shown in Fig. 6.

The Review of Physical Chemistry of Japan Vol. 37 (1967)

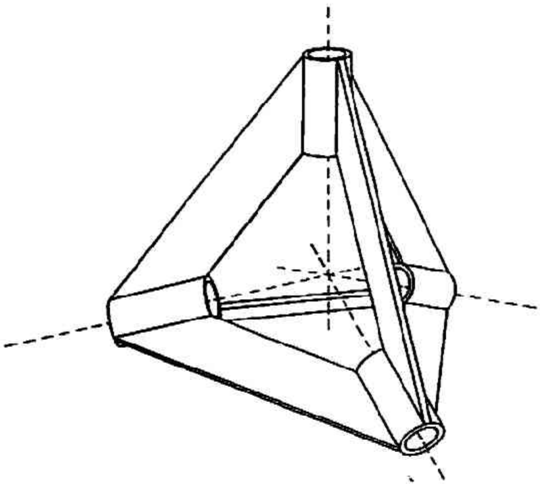

Fig. 6 "Sure-Guide" for ultra precise anvil positioning in RITB tetrahedral press
Similar sure-guides can be used with cubic and other multianvil high pressure apparatus.

for use with RITB tet presses. The sure-guide fits around the anvil posts of Fig. 1 at a distance sufficiently removed from the anvils to be out of the way. As the anvils move in and out with respect to the center of the press, the anvil posts slide within the bearing surfaces of the sure-guide. This bearing surface may be electrically insulating. Obviously the sure-guide principle pictured for a tet press in Fig. 6 can be used with cubic, octahedral, prismatic and other RITB multianvil presses.

The illustrations of this article show hydraulically impelled rams or jacks as means for activating the press. It is evident that mechanical, electrical or any other means of motive power may be used to actuate a RITB press while still maintaining the novel advantages and features enumerated above.

Brigham Young University
Provo, Utah 84601