Jan. 13, 1970 | B. I. BROWN | 3,488,990

HIGH ENERGY RATE FORMING MACHINE

Filed Feb. 27, 1967 | 8 Sheets-Sheet 1

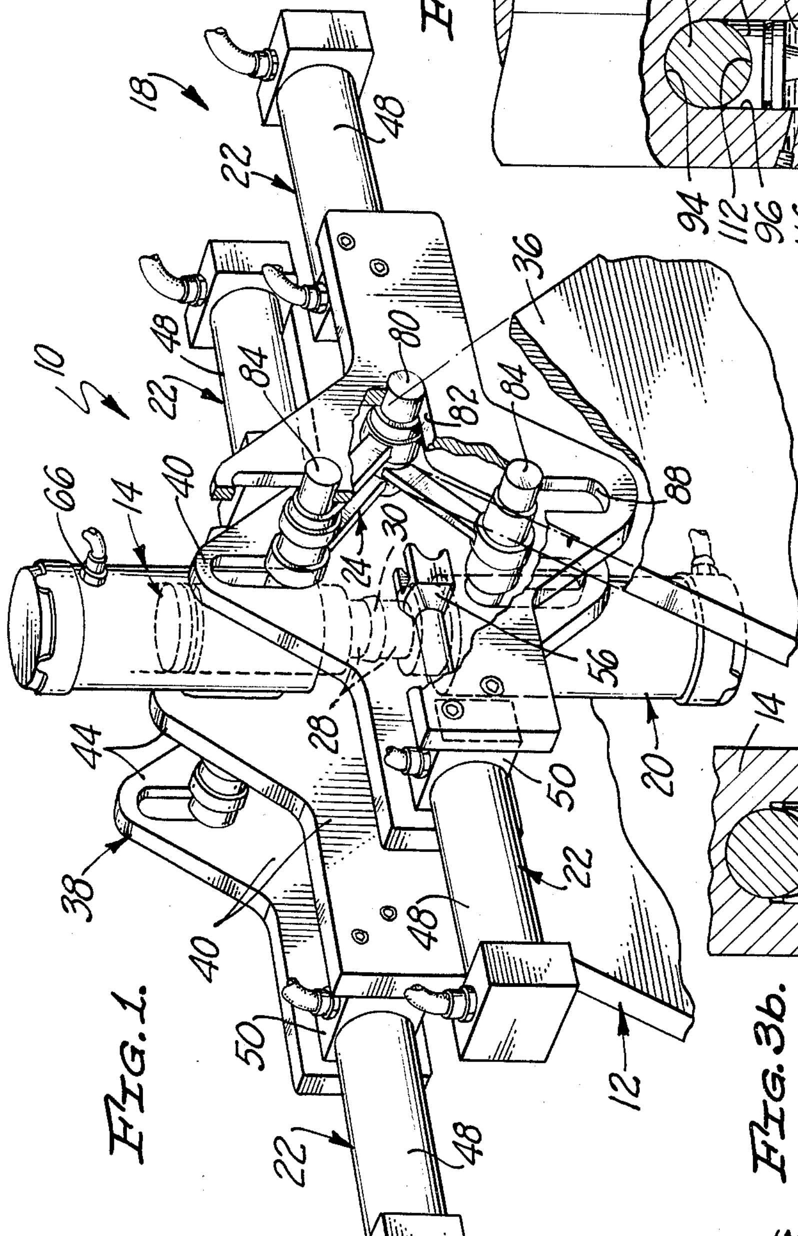

FIG. 1.

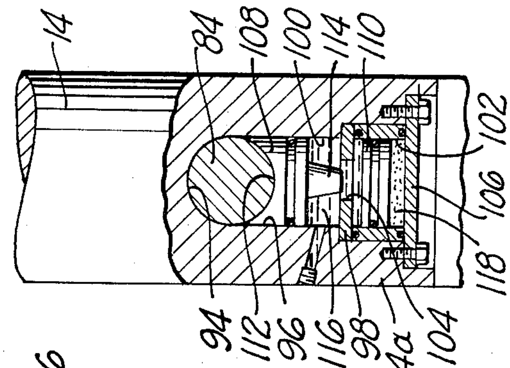

FIG. 3a.

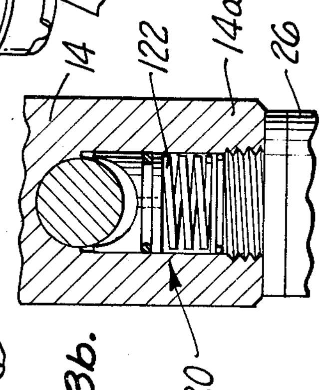

FIG. 3b.

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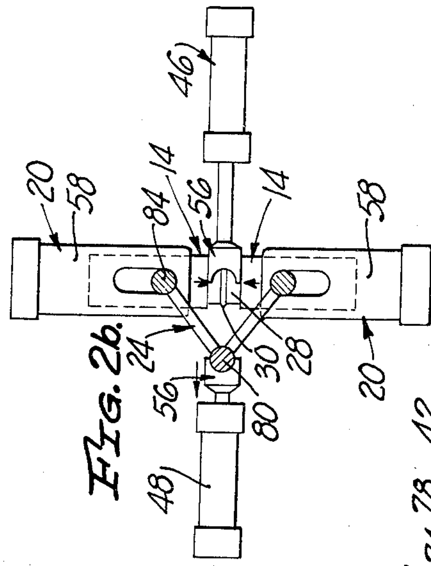

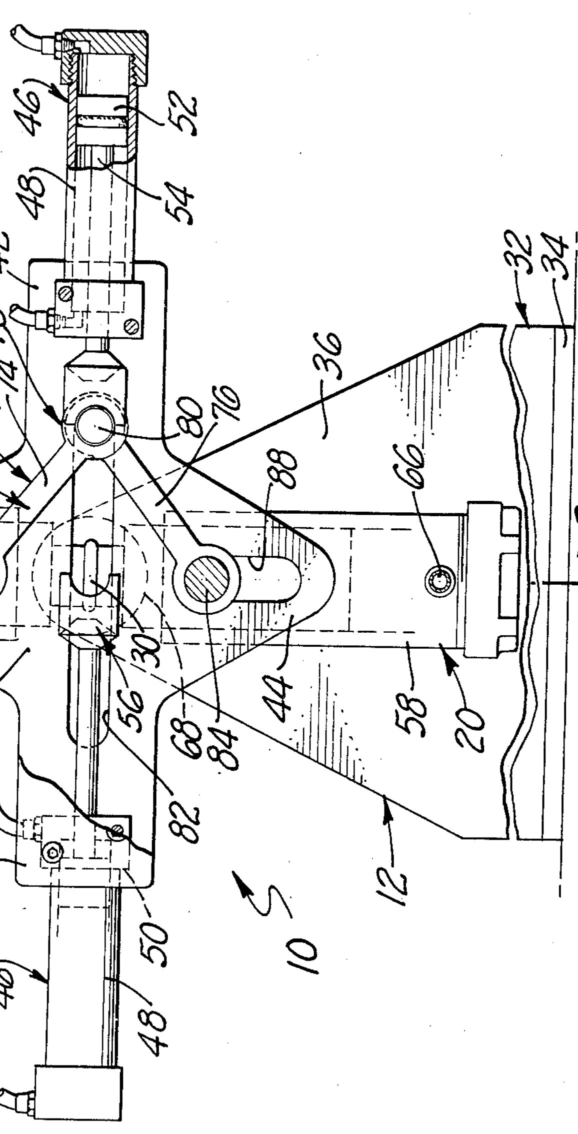

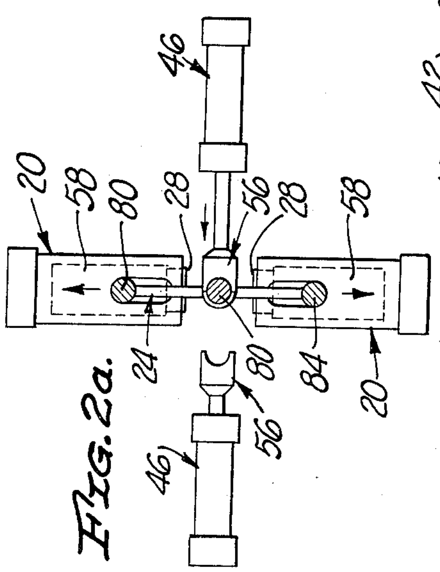

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FIG. 3.

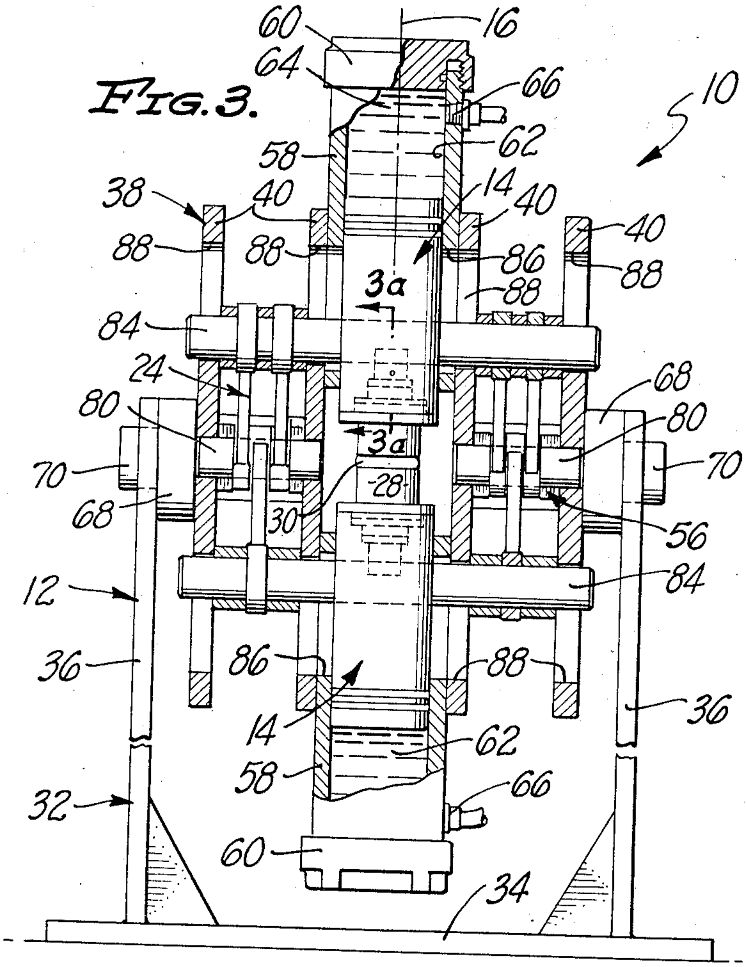

FIG. 4.

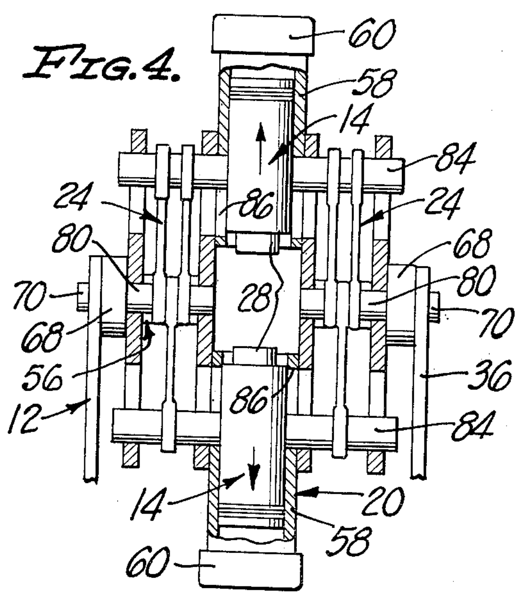

FIG. 5.

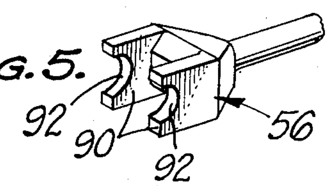

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FIG. 7.

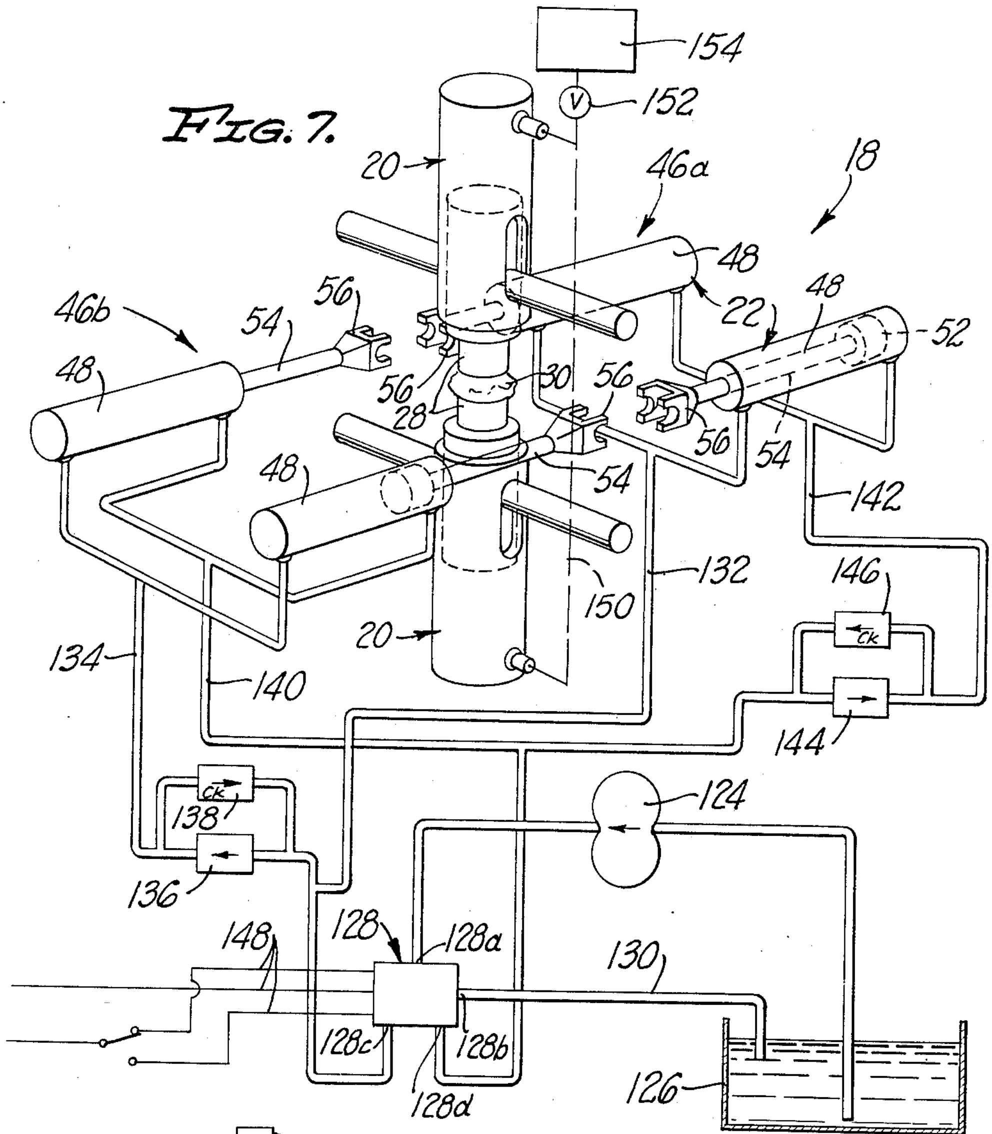
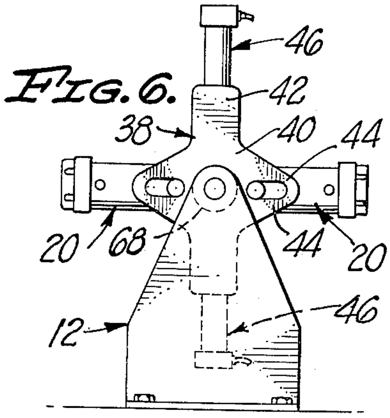


FIG. 6.



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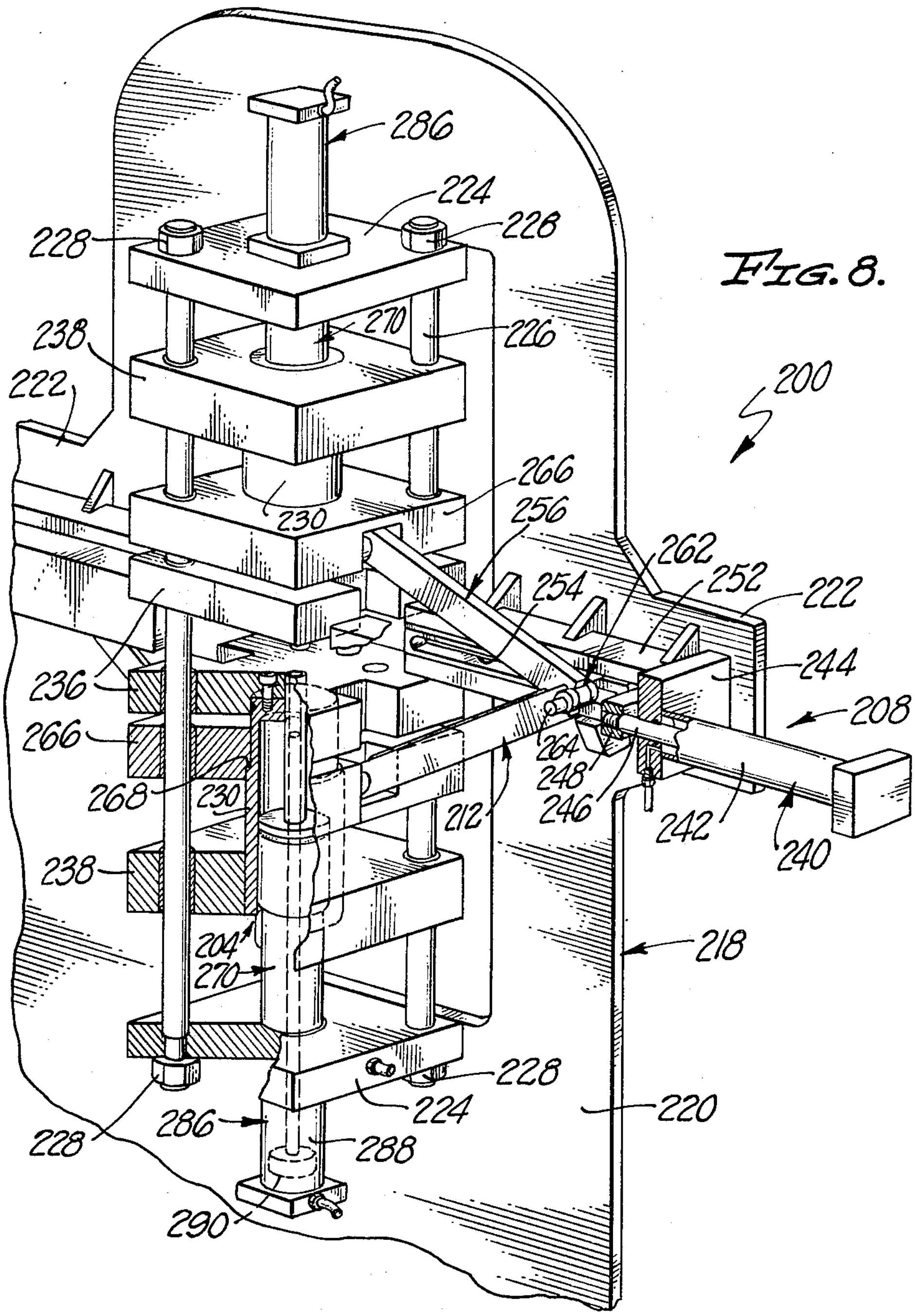

FIG. 8.

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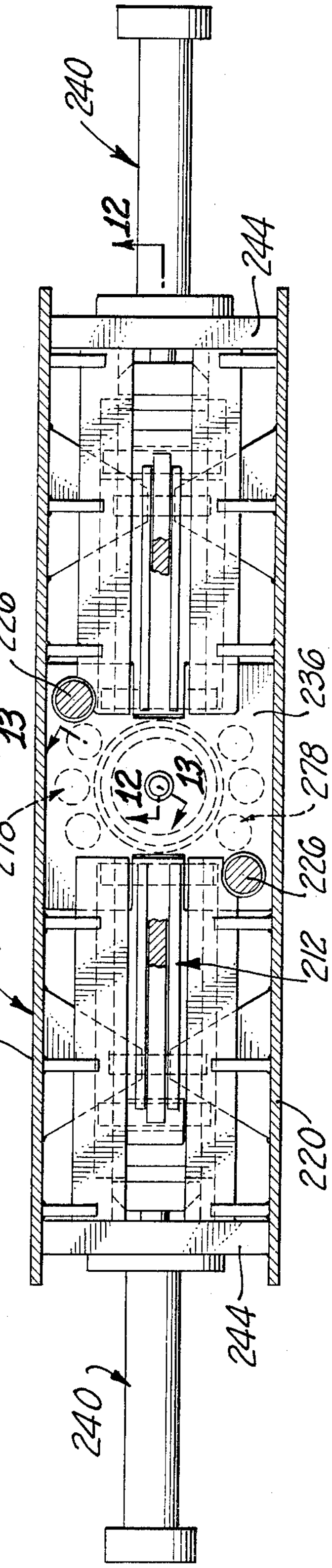

FIG. 11.

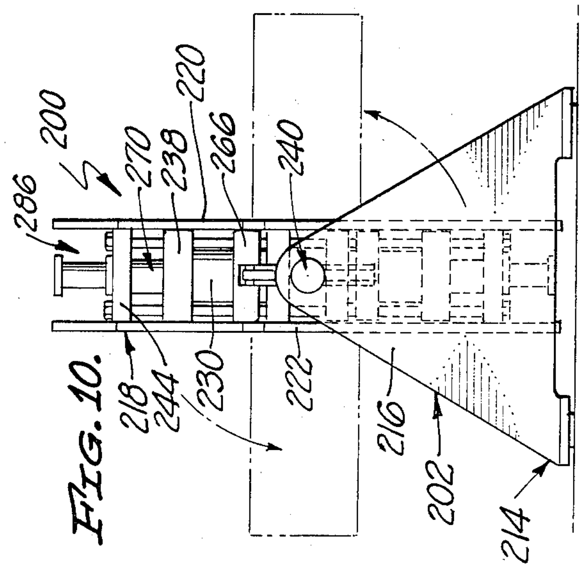

FIG. 10.

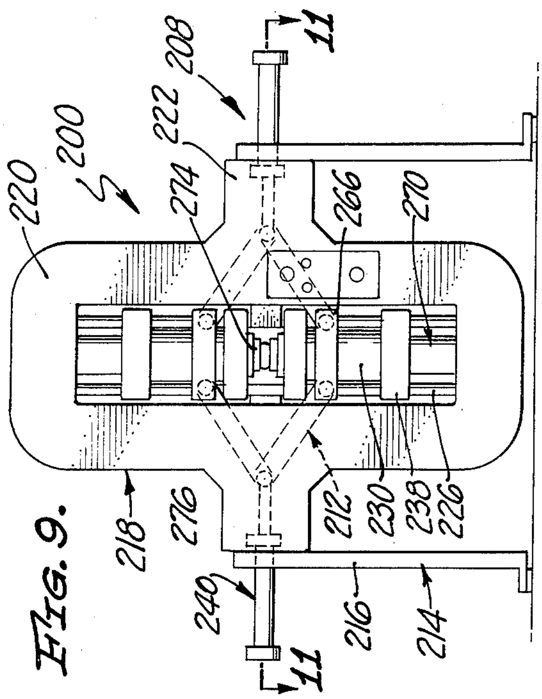

FIG. 9.

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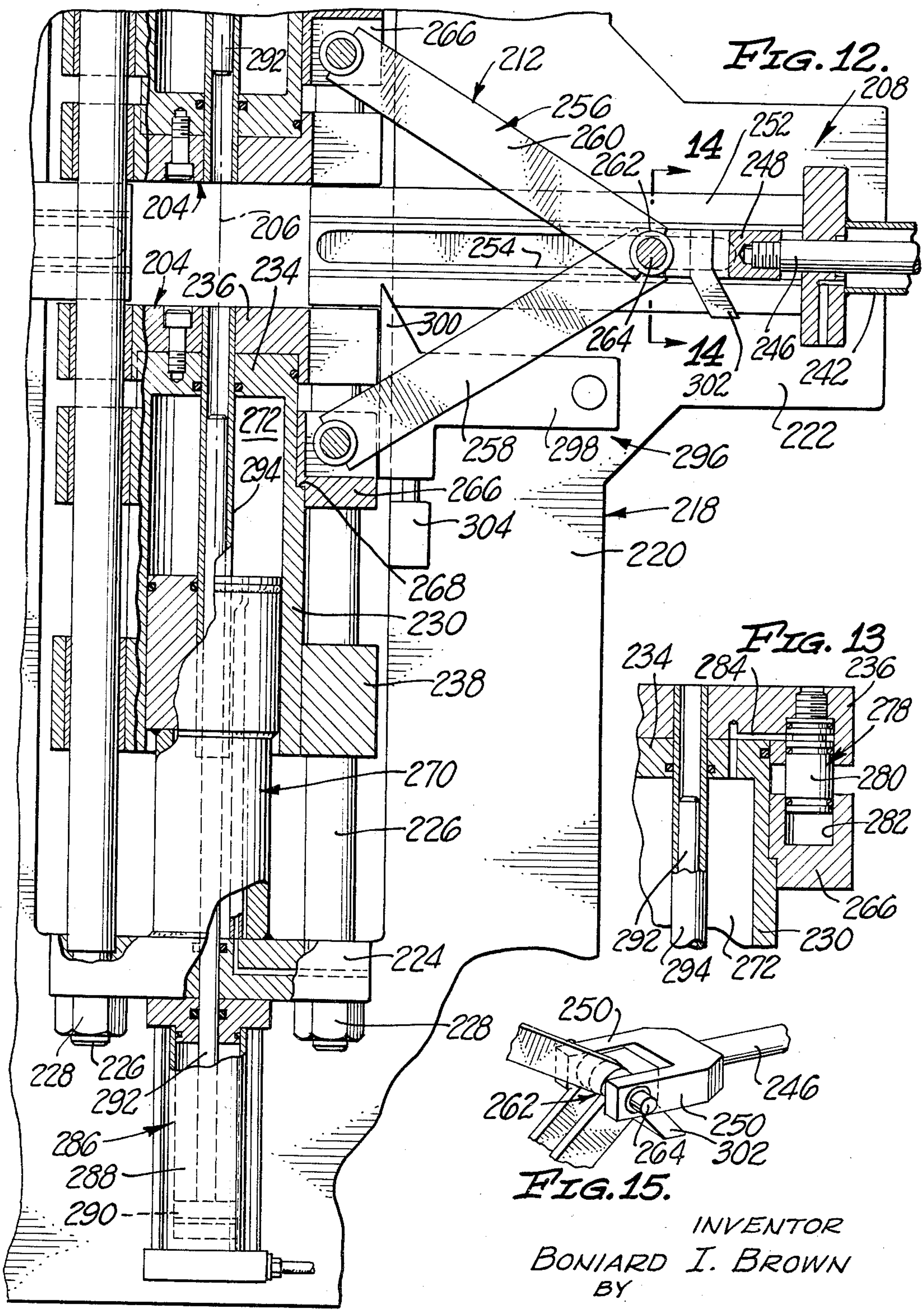

FIG. 12.

FIG. 13

FIG. 15.

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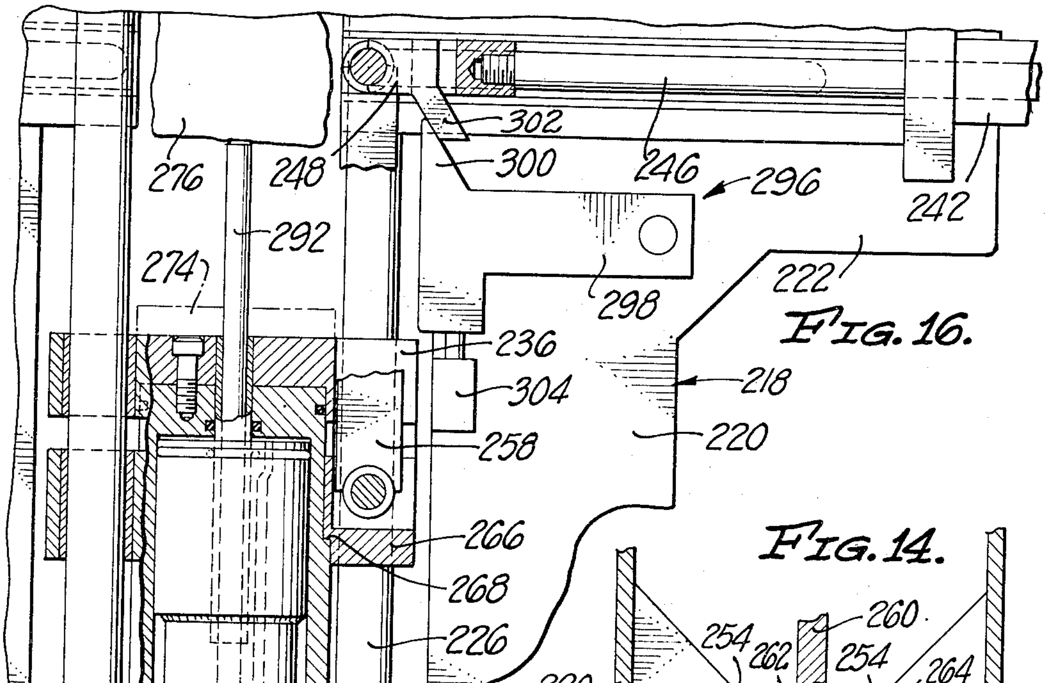

FIG. 16.

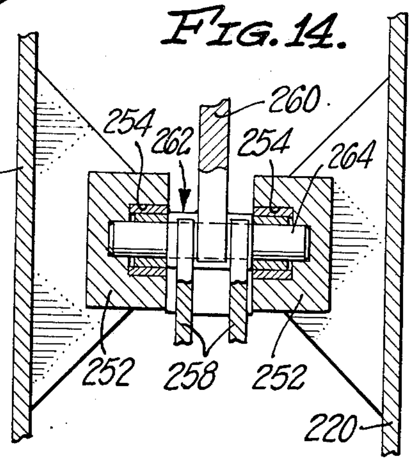

FIG. 14.

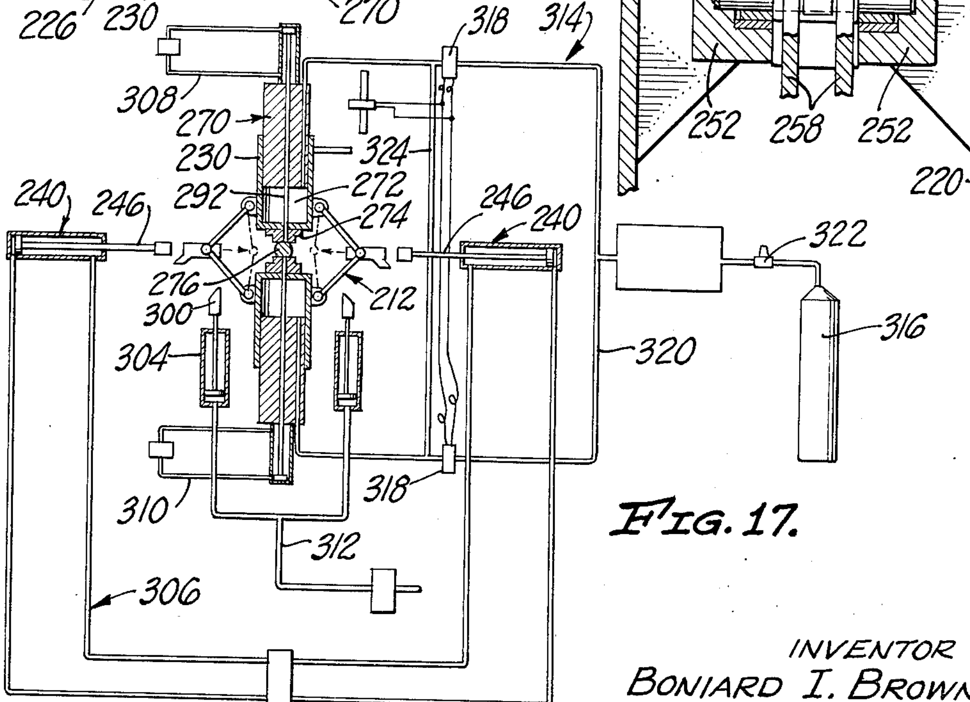

FIG. 17.

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United States Patent Office 3,488,990 Patented Jan. 13, 1970

3,488,990

HIGH ENERGY RATE FORMING MACHINE

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Filed Feb. 27, 1967, Ser. No. 618,876
Int. Cl. B21d 7/06; B21j 9/18, 7/36
U.S. Cl. 72—407 16 Claims

ABSTRACT OF THE DISCLOSURE

An impact or high energy rate forming machine having a pair of opposing rams adapted to be impelled toward each other, and having mechanical linkage, preferably a toggle linkage, for synchronized ram action.

This invention relates generally to machines for impact forming metals and other work materials; more particularly, the present invention relates to improvements in impact forming machines of the kind which are characterized by a pair of opposing forming rams adapted to be driven toward one another to impact form a workpiece therebetween.

As will appear from the ensuing description, the improved impact forming machine of the invention may be employed for a variety of impact forming applications. In this regard, it should be noted at the outset that the expression "impact forming," as it is used herein, is intended to encompass any and all impact forming operations which involve percussive contact of opposing, coacting forming elements with an intervening workpiece to mold, shear, deform, punch, or otherwise work or form the workpiece. However, the present forming machine is intended primarily for so-called high energy rate forming applications. For this reason, the invention will be described in connection with such high energy rate forming applications.

Generally speaking, high energy rate forming of a workpiece involves placement of the workpiece within the cavity of a forming die and subsequent high velocity impulsion of the die and a forming ram toward one another to bring the ram and the workpiece into percussive contact of such extremely high kinetic energy and short time duration that the material of the workpiece undergoes plastic deformation into conformance with the die cavity. In some high energy rate forming machines, the forming die is effectively stationary and the forming ram is driven toward the die to effect the high energy rate forming action, just explained. High energy rate forming machines of this type, however, particularly those adapted for repetitive cycling operation, are characterized by certain disadvantages. Thus, primarily because of the high energy rates, stresses, and ram velocities involved in high energy rate forming, problems of unreliability, maintenance, and short service life have been general. These problems have been particularly serious with respect to impact loading and inability to isolate static machine components from such loading and high rate stresses. Generally speaking, efforts to relieve these problems have involved relatively complex and specialized machine structures and mechanisms which are relatively massive as well as difficult and costly to fabricate.

Moreover, the ram of these forming machines tends to rebound after its initial forming impact with the workpiece in such a way that the workpiece is subjected to several succesive blows by the ram. Such repeated impact of the ram against the formed workpiece results in damage to the workpiece and produces additional stresses in the machine. Another disadvantage of the high energy rate forming machines of the kind under discussion is their relatively low efficiency. This low efficiency is due, in large part, to the energy losses which typically occur during operation of these machines. A further disadvantage of the existing forming machines resides in the inaccessibility and difficulty of servicing, replacing, or repairing machine components, particularly the annular sealing elements which are utilized in the pressure chambers of many forming machines.

Improved high energy rate forming machines have been devised which avoid the above noted and other disadvantages of the single ram forming machines. These improved forming machines are characterized by a pair of opposing forming rams which are impelled toward one another to effect high energy rate forming of a workpiece situated between the rams. Such dual ram high energy rate forming machines are so constructed and operated that the forming rams possess approximately the same kinetic energy at impact. Accordingly, substantially all of the kinetic energy of the rams is absorbed by the rams themselves and the intervening workpiece, and the rams are arrested at the conclusion of their forming strokes without any appreciable stressing or shock loading of the machine frame or the other machine components. Such dual ram high energy rate forming machines, therefore, are characterized by improved reliability, longer service life, greater simplicity of construction, lower cost of manufacture, immunity to breakdown, ease of repair, replacement, and servicing the machine components, when necessary, superior product formation, and other highly desirable operating characteristics.

It is obvious at this point that optimum operation of a dual ram high energy rate forming machine requires precise matching of the kinetic energies of the forming rams at impact. The kinetic energy of each forming ram, of course, is a combined function of its mass and velocity. Some existing forming machines of this kind utilize forming rams of substantially equal mass. In this case, matching of the ram energies requires precise equalizing of the ram velocities at impact. Other high rate energy forming machines of the kind under discussion employ forming rams, or the like, of different mass. Matching of the kinetic energies of the rams in these latter machines requires precise differential ram velocities at impact. Precise control of the ram velocities at impact, then, is essential to optimum operation of both types of dual ram high energy rate forming machines.

One of the outstanding deficiencies of the existing dual ram forming machines resides in the fact that such precise control of the ram velocities at impact is difficult or impossible to achieve. This is due to the fact that the existing machines are devoid of any means to positively synchronize release of the rams and subsequent movement of the rams through their forming strokes. Thus, a typical high energy rate forming machine of the kind under discussion includes means which cooperate with the forming rams to define expansible pressure chambers containing a working fluid, such as nitrogen and means for compressing the working fluid to a high pressure when the rams are retracted. This working fluid is effective, upon release of the rams, to impell the rams toward one another at high velocity, thus to accomplish the high energy rate forming action, discussed earlier. Owing to the fact that the forming rams are capable of independent movement, to the high velocities to which the rams are accelerated, and to the extremely short time duration of the working strokes of the rams, the various parameters which affect or govern the ram velocities at impact are extremely critical. For example, since the rams are accelerated from rest, the ram velocities at impact are functions of the time duration or length of the working strokes of the rams. Accordingly, even though the rams are impelled at the correct rates of acceleration to achieve precise matching of the ram energies at impact, actual energy matching will occur only if release of the rams is precisely synchronized, such that the working strokes of the rams are of precisely the correct time duration and length and impact occurs at a precisely predetemined position along the direction line of ram travel. Thus, a delay, even on the border of a few microseconds, in the release of one ram will result in a reduced working stroke and impact velocity of the delayed ram and a correspondingly increased working stroke and impact velocity of the other ram. Under these conditions, the kinetic energy of the delayed ram at impact will be less, and the energy of the other ram will be greater, than that required for precise matching of the ram energies at impact. Accordingly, the machine frame and its supporting floor may be subjected to shock loading and resulting high stresses. Similar undesirable results may obtain if the rams, even though properly released, are subjected to improper working fluid pressure or to retarding forces which prevent normal acceleration of the rams.

It is obvious, of course, that the various parameters which affect the ram velocities at impact in the existing dual ram high energy rate forming machines are extremely critical, as just stated, for the reason that the ram movements are not mechanically or positively synchronized. Accordingly, precise control of these parameters is necessarily relied on to achieve matching of the ram energies. This precise control, however, is extremely difficult to achieve, particularly in a high energy rate forming machine designed for repetitive cycling, and requires a forming machine which is rather complex in construction, costly to manufacture, difficult to maintain in the proper state of adjustment, and is otherwise not totally satisfactory.

One important aspect of this invention is concerned with an improved impact forming machine, which is particularly designed for high energy rate forming applications, wherein the forming rams are operatively connected by mechanical linkage means in such a way as to effect precisely synchronized release and/or precisely synchronized travel of the rams from their retracted positions to their forming positions. Precise matching of the kinetic energies of the rams at impact is thereby attained with a forming machine of utmost simplicity, minimum cost, maximum reliability, and optimum repetitive cycling capability

Some of the existing dual ram high energy rate forming machines of the kind under discussion are subject to another deficiency which this invention also seeks to overcome. The forming machines referred to here are of the type wherein the working fluid is partially or totally pressurized to its high initial working pressure by retraction of the forming rams. These machines comprise power means, such as hydraulic or pneumatic rams, for retracting the forming rams against the pressure of working fluid sealed within the expansible ram driving chambers. The rams are then latched in their retracted positions to condition the machines for a subsequent high energy rate forming cycle. The existing machines of this kind are not totally satisfactory for the reason that the ram

retracting means employed therein are devoid of any mechanical force multiplying or amplifying structure and are thus required to operate at a relatively high pressure. The existing ram retracting means, therefore, tend to be quite massive, complex in construction, costly to manufacture, and impose undesirable drag or retarding forces on the forming rams. Moreover, many of these existing forming machines require one means for retracting the rams and completely separate means for locking the rams in their retracted positions.

According to another of its important aspects, the present invention provides a high energy rate forming machine equipped with improved means for retracting the rams against the pressure of working fluid in the expansible ram driving chambers, thus to compress the working fluid to the high pressure level required for optimum high energy rate forming operation of the machine. These ram retracting means develop a mechanical advantage which permits the retracting means to be powered by a relatively small power source, such as a low pressure hydraulic or pneumatic actuator, that is relatively compact, economical to manufacture, and imposes minimal drag on the forming rams during their forming strokes. An additional feature of the preferred form of the invention resides in the fact that the mechanical advantage of the retracting means increases as the forming rams approach their retracted positions and, therefore, as the pressure of the working fluid increases. Moreover, the present ram retracting means may serve the multiple function of retracting the rams against working fluid pressure, retaining the rams in their retracted positions in readiness for a subsequent high energy rate forming cycle of the machine, and simultaneously releasing the rams for movement through their forming strokes.

A further important aspect of the invention is concerned with a high energy rate forming machine wherein the several improved machine functions heretofore stated are accomplished by a unique toggle which is operatively connected between the forming rams. This toggle is effective, when driven to its dead center position, to simultaneously retract the forming rams against working fluid pressure with a mechanical advantage which increases as the rams approach their retracted positions. The toggle, when released for movement from its dead center position, is effective to constrain the rams for precisely synchronized movement to their forming positions. Precise matching of the kinetic energies of the rams at impact is thereby achieved, whereby shock loading of the machine frame and its supporting floor is virtually eliminated. The complexity and cost of the forming machine is also greatly reduced. Moreover, the toggle connection between the forming rams uniquely adapts the present forming machine to relatively high rate repetitive cycling suitable for production line operation. As will appear from the ensuing description, one disclosed embodiment of the invention is particularly adapted to such high rate repetitive cycling operation.

A further advantage of the forming ram retraction and synchronizing means embodied in the present invention resides in the fact that not only may the kinetic energies of the rams at impact be precisely matched or balanced, as noted earlier, but further, these ram energies may be regulated to provide a work forming impact of any desired intensity. This feature of the machine adapts the latter to high energy rate forming of a great variety of work materials and shapes and enables the machine to form finished work products which are superior to those produced by the existing high energy rate forming machines.

A particularly important advantage of the present forming machine is its superiority to the existing forming machines from the standpoint of safety. Thus, in the existing dual ram forming machines, the forming rams are capable of independent movement, as already noted. As a consequence, it is possible that one ram may jam in a stationary position along its forming stroke, while the remaining ram continues its high velocity forming movement. Under these conditions, the ram energies at impact are not matched and the machine may suffer severe damage. More serious, however, particularly in high energy rate forming applications, is the fact that high velocity unbalanced impact of a moving ram against the stationary ram may cause disintegration of the forming machine and thus create an extremely serious safety hazard. The present improved forming machine construction avoids these hazards of the existing forming machines. Thus, since the forming ram movements are positively synchronized in the present machine, jamming of one ram will either arrest the other ram, or the moving ram will free the jammed ram. In either case, impact of the forming rams without matching or balancing of the ram energies, and hence the hazards attendant to unbalanced ram impact, are avoided.

It is a general object of the invention, therefore, to provide an improved dual ram impact forming machine which is particularly suited for high energy rate forming applications.

A more specific object of the invention is to provide an improved impact forming machine of the character described wherein the forming rams are interconnected by mechanical linkage means which effect precisely synchronized release of the rams from their retracted positions and/or precisely synchronized travel of the rams through their forming or working strokes, in such manner as to achieve precise matching or balancing of the kinetic energies of the rams at impact, thereby to minimize or eliminate impact loading and the attendant high stresses on the machine frame and its supporting floor, eliminate the safety hazards associated with high energy rate forming machines having independently movable rams, prolong the service life of the machine, minimize the possibility of machine failure, improve the operating reliability of the machine, permit regulation of the ram energies at impact, and enhance the quality of the work product produced by the machine.

Another object of the invention is to provide a high energy rate forming machine wherein retraction of the forming rams is utilized to compress a working fluid to a high pressure level for subsequently impelling the rams through their forming strokes and wherein further the machine is equipped with novel force multiplying means for retracting the rams against working fluid pressure, thus to permit actuation of the ram retracting means with a power source of minimum size.

A related object of the invention is to provide a forming machine according to the foregoing object wherein the mechanical advantage of the ram retracting means increases as the rams approach their fully retracted positions, whereby the effective retracting force on the rams increases as the opposing force of the compressed working fluid increases.

Yet another object of the invention is to provide an improved impact forming machine of the character described wherein the ram releasing, synchronizing, retracting, and force multiplying functions of the machine are performed by a unique toggle connection between the forming rams.

A further object of the invention is to provide an improved impact forming machine of the character described which is uniquely adapted to repetitive cycling operation.

A still further object of the invention is to provide an improved impact forming machine of the character described wherein the forming ram structure of the machine is rotatable to a horizontal attitude, thus to neutralize the affect of gravity on the ram structure.

Yet a further object of the invention is to provide an improved impact forming machine of the character described which is relatively simple in construction, light weight, compact, economical to manufacture, reliable in operation, safe to use, and is otherwise ideally suited to its intended purposes.

Other objects, features and advantages of the present invention will become apparent to those versed in the art from a consideration of the following description, the appended claims and the accompanying drawings, wherein:

FIGURE 1 is a perspective view, partially broken away, of an improved impact forming machine according to the invention;

FIGURE 2 is a side elevation of the machine with parts broken away for the sake of clarity;

FIGURE 2*a* is a view similar to FIGURE 2, on reduced scale, illustrating the machine parts in one operative position;

FIGURE 2*b* is a view similar to FIGURE 2*a* illustrating the machine parts in another operative position;

FIGURE 3 is a section taken on line **3—3** of FIGURE 2 illustrating the forming rams of the machine in their extended forming positions;

FIGURE 3*a* is an enlarged section taken on line **3*a*—3*a*** in FIGURE 3 and illustrating a wrist pin cushioning means embodied in the forming machine;

FIGURE 3*b* is a section similar to FIGURE 3*a* illustrating a modified wrist pin cushioning means;

FIGURE 4 is a section similar to FIGURE 3, on reduced scale, illustrating the forming rams in their retracted positions;

FIGURE 5 is a perspective view of a bearing fork which is utilized in the machine;

FIGURE 6 is a side elevation of the machine, on reduced scale, illustrating the ram structure of the machine rotated through 90° from its position of FIGURE 1;

FIGURE 7 diagrammatically illustrates the hydraulic circuitry of the machine;

FIGURE 8 is a perspective view, partially broken away, of a modified impact forming machine according to the invention;

FIGURE 9 is a reduced front elevation of the modified forming machine;

FIGURE 10 is a reduced side elevation of the modified forming machine;

FIGURE 11 is an enlarged section taken on line **11—11** in FIGURE 9;

FIGURE 12 is an enlarged section taken on line **12—12** in FIGURE 11;

FIGURE 13 is an enlarged section taken on line **13—13** in FIGURE 11;

FIGURE 14 is a section taken on line **14—14** in FIGURE 12;

FIGURE 15 is a perspective detail of a toggle knee joint embodied in the modified forming machine;

FIGURE 16 is a fragmentary view illustrating certain parts of the machine, shown in FIGURE 12, in other operative positions; and

FIGURE 17 diagrammatically illustrates the hydraulic circuitry of the modified forming machine.

Referring to the drawings in general terms, impact forming machine **10** which has been selected for illustration in FIGURES 1 through 7 of these drawings comprises a frame **12** mounting a pair of forming rams **14** for movement relative to the frame along a common direction line **16**. Rams **14** are movable between remote retracted positions, shown in FIGURE 4, and proximate forming positions, shown in FIGURE 3. Associated with the forming rams **14** are retracting means **18** for driving the rams from their forming positions to their retracted positions, and driving or impulsion means **20** for driving or impelling the rams from their retracted positions to their forming positions. In the particular forming machine illustrated, the ram impulsion means **20** comprise a working fluid, which is compressed to a high pressure level by retraction of the rams and subsequently impells the rams to their forming positions. The strokes of the forming rams **14** which involve movement of the rams from their retracted positions to their forming positions are referred to herein as their forming or working strokes.

The ram retraction means **18** comprise power means **22** for producing a ram retraction force and linkage means **24** for mechanically amplifying the retraction force and transmitting the amplified force to the forming rams **14** in directions to retract the rams. In the illustrated forming machine, the linkage means **24** serve the additional functions of retaining the forming rams **14** in the retracted positions against the thrust of the ram driving or expulsion means **20** to condition the machine for subsequent forming strokes of the rams, synchronizing release of the rams from their retracted positions to initiate these forming strokes, and synchronizing movement of the rams through their forming strokes to equalize the ram impact velocities. The forming rams **14** are matched so as to have equal mass. Accordingly, when the rams are impelled through their forming strokes by the ram impulsion means **20**, the rams arrive at their forming positions of FIGURE 3 with equal kinetic energy.

The forming rams **14** have confronting working ends **14***a* mounting die holders **26**. Releaseably secured in these die holders are work forming dies **28**. These work forming dies have mating die cavity shapes (not shown) which define a die cavity having the desired shape of the finished work product when the forming dies are placed in contact.

Briefly, a typical impact forming cycle of the illustrated impact forming machine **10** involves initial activation of the ram retracting means **18** to drive the forming rams **14** to their retracted positions of FIGURE 4. At some point in this retraction stroke of the forming rams, a workpiece **30** is placed within the cavity of one of the forming dies **28**. As noted earlier, retraction of the forming rams **14** occurs against the thrust of the ram driving or impulsion means **20** and conditions these means for subsequently impelling the rams to their forming positions. An important feature of the invention resides in the fact that mechanical advantage of the ram retracting and synchronizing linkage means **24** permits the use of relatively small compact power means **22** for retracting the rams, thus minimizing the complexity, cost, and overall size and weight of the machine. Moreover, as will appear from the ensuing description, the linkage means **24** are uniquely constructed and arranged to permit both maximum utilization of the impact energy of the forming rams **14** and regulation of this impact energy, thus to adapt the machine for impact forming a wide variety of work materials and shapes.

After the forming rams **14** have been fully retracted, they are released for impulsion through their forming or working strokes by the thrust of the ram driving or impulsion means **22**. As the rams approach the ends of these forming strokes, the forming dies **28** on the working ends **14***a* of the forming rams **14** enter into percussive work forming relation in such a way that the workpiece **30** is deformed into conforming relation with the die cavity defined by the forming dies. The illustrated forming machine is a high energy rate forming machine wherein the forming rams **14** are driven through their forming strokes at sufficiently high velocity to cause high energy rate forming of the workpiece **30**. As noted earlier, during such high energy rate forming of a workpiece, the material of the workpiece undergoes plastic flow into conformance with the die cavity. As is well known in the art, such high energy rate forming may be utilized to form to a desired finished shape, with great precision, a variety of relatively hard work materials, including both metallic and non-metallic materials, which are extremely difficult or impossible to form in any other way.

A highly important feature of the illustrated forming machine **10** resides in the equal masses of the forming rams **14** and the accurately synchronized movement of the rams through their forming strokes to achieve equal impact velocities of the rams, as noted earlier. Thus, this precise matching of the ram masses and velocities effects precise matching of the kinetic energies of the rams at impact. As a consequence, the machine frame and its supporting floor are not subjected to any appreciable shock loading so that it is unnecessary to provide the machine with the usual rugged foundation required by many high energy rate impact forming machines. The precise matching or balancing of the kinetic impact energies of the forming rams **14** which is achieved in the present forming machine by virtue of the positively synchronized forming movements of the rams also permits a relatively light weight, low cost machine construction as well as convenient machine installations which have hitherto been impossible, owing to the massive size and weight of the existing machines. In the illustrated forming machine, for example, the forming ram structure is pivotally mounted to enable rotation of the ram structure to any desired angular position or attitude. The forming ram structure may, for instance, be rotated to a horizontal attitude to eliminate the affect of gravity on the rams.

Referring now in greater detail to the illustrated forming machines **10**, the machine frame **12** comprises a lower base portion **32** including a bottom mounting plate **34** and spaced parallel plate-like arms **36** rising from the mounting plate. Positioned between the upper ends of the base arms **36** is an upper frame structure **38** including four essentially identical, generally cruciformed shaped frame plates **40**. Each frame plate **40** has a first pair of aligned, oppositely directed arms **44** extending at right angles to the arms **42**. The several frame plates **40** are oriented with their corresponding arms **42** and **44** aligned in directions normal to the plates, as shown. The power means **22** for retracting the forming rams **14** includes four fluid pressure actuators **46** having cylinders **48** extending lengthwise of and positioned at their inner ends between the outer ends of the arms **42** of the two outer frame plates and the adjacent inner frame plates **40**, as shown. The inner ends of these actuator cylinders have external rectangular shoulders **50** which seat flush against the confronting surfaces of and are bolted or otherwise rigidly joined to the adjacent frame plates **40**, thus to rigidly join each outer frame plate to its adjacent inner frame plate. The two actuator cylinders **48** between each outer frame plate and the adjacent inner frame plate are coaxially aligned and extend in opposite directions from the plates, as shown.

Each actuator cylinder **48** contains a piston **52** having a rod **54** which extends through the inner end of the respective cylinder. Fixed on the inner end of each piston rod is a bearing fork or clevis **56**. The operation of the actuators **46** will be explained presently.

The forming ram drive or impulsion means **20** comprise coaxial ram cylinders **58** which extend lengthwise of and are positioned at their inner ends between the outer ends of the arms **44** of the two inner frame plates **40**. The ram cylinders **58** are welded or otherwise rigidly attached to the inner frame plates and thus serve to rigidly join these plates to one another. The inner ends of the ram cylinders **58** open toward one another. The outer end of the ram cylinders are closed by end caps **60**. The forming rams **14** comprise cylindrical pistons which slide in the ram cylinders **58**, respectively. The forming rams **14** and the ram cylinders **58** cooperatively define expansible pressure chambers **62** containing a working fluid **64**, such as gaseous nitrogen. Other possible working fluids are certain liquids, such as Texaco Regal B. In the event that a liquid is employed as a working fluid, neoprene balls filled with nitrogen may be placed in the pressure chambers **62** with the liquid to provide controlled, extended release of the energy contained in the working liquid when compressed. In the outer ends of the ram cylinders **58** are fluid ports **66** through which the working fluid may be introduced into the pressure chambers **62**. It is significant to note at this point that retraction of the forming rams **14** in the ram cylinders **58** is effective to reduce the volume of the expansible pressure chamber **62** and thereby compress the working fluid **64** in the chambers. In most high energy rate forming applications, the working fluid **64** is introduced into the pressure chamber **62** under initial pressure such that the working fluid is elevated to a working pressure on the order of 2,000 p.s.i. by retraction of the forming rams **14**.

It is evident at this point that the actuator and ram cylinders **48**, **58** rigidly join the frame plates **40** to form the integral upper frame structure **38**. Rigidly joined to the outer sides of the two outer frame plates **40**, at the centers of these latter plates, are cylindrical bosses **68** from which extend coaxial journals or trunnions **70**. These trunnions are rotatably supported in the upper ends of the upstanding frame base arms **36** and serve to pivotally mount the upper frame structure **38** on the frame base **32** for turning on the horizontal axis of the trunnions.

The illustrated ram retracting and synchronizing linkage means **24** comprise a pair of toggles **72** located at opposite sides of the ram cylinders **58**, within the spaces between the two outer frame plates **40** and the adjacent inner frame plates. Each toggle has a pair of toggle bars **74**, **76**, the adjacent ends of which are pivotally joined by a knee joint **78** including a knee shaft **80**. The ends of the toggle knee shafts **80** project beyond their respective toggle bars **74**, **76** into aligned guide tracks or slots **82** in the adjacent frame plates **40**. These guide slots are disposed in a common plane containing the axes of the ram actuator cylinders **48**. The outer ends of the toggle bars **74**, **76** are pivotally attached to the forming rams **14**. To this end, the rams are provided with transverse wrist pins **84** which extend through axial guide slots **86** in the ram cylinders **58** and aligned guide slots **88** in the frame plates **40**. The ram cylinder slots **86** and the frame plate slots **88** are disposed in a common plane normal to the longitudinal axes of the actuator cylinders **48** and containing the common axis of the ram cylinders **58**. The outer ends of the toggle bars **74**, **76** are rotatably secured to the wrist pins **84** in the regions between the outer and adjacent inner frame plates **40**.

It is now evident that the toggles **72** interconnect the forming rams **14** in such a way as to constrain these rams to precisely synchronized movement between their retracted positions of FIGURE 4 and their forming positions of FIGURE 3. As the rams travel back and forth between these positions, the toggle knee shafts **80** and wrist pins **84** slide back and forth along their respective frame plate guide slots. It is significant to note here that the toggle knee joints **78** are movable between the extreme or limiting positions illustrated in FIGURES 2 and 2*b* and through the intervening dead center position illustrated in FIGURE 2*a*. In this dead center position, the knee joints are located in a plane containing the toggle wrist pins **84**. Movement of the toggle knee joints **78** from either limiting position to the dead center position is obviously effective to drive the formng rams **14** from their forming positions to their retracted positions with a mechanical advantage which increases sharply as the rams approach their retracted positions. Movement of the forming rams from their retracted positions to their forming positions with the toggle knee joints initially slightly offset from their dead center positions, in turn, is effective to drive these knee joints to their adjacent limiting positions.

It will be recalled that the piston rods **54** of the ram actuators **46** mount bearing forks **56**. These bearing forks have spaced fork arms **90** formed with outwardly opening, generally semi-circular bearing recesses **92** and are adapted to rotatably seat against the adjacent toggle knee joints **78** in straddling relation to the toggle bars **76**. The toggle bars **74** are longitudinally slotted to straddle the bearing forks **56**. Suitable keying means (not shown) are provided within the actuator cylinders **48** for retaining the bearing forks **56** in the proper attitude for seating against the toggle knee joints **78**, in the manner best illustrated in FIGURE 2.

As noted earlier and hereinafter explained in greater detail, the forming rams **14** are driven or impelled at high velocity from their retracted positions to their forming positions to effect impact forming of the workpiece **30** within the cavity defined by the forming dies **28**. This impact forming action abruptly arrests the forming rams **14** at the conclusion of their high velocity forming strokes. It is obvious, of course, that during these high velocity forming strokes, the toggle wrist pins **84** and the toggle bars **74**, **76** connected to the wrist pins acquire substantial kinetic energy. Accordingly, the wrist pins are subjected to severe deceleration forces upon arresting of the forming rams after impact. If the wrist pins were rigidly secured to the forming rams, as by press fitting the pins into the rams, for example, the forces active on the pins at impact might bend the outer extending ends of the pins or "Brinell" the pins into their bearing seats within the forming rams. For this reason, the forming rams **14** are preferably equipped with shock absorbing means for arresting the wrist pins without excessive shock at the conclusion of the ram forming strokes.

FIGURE 3*a* illustrates one possible shock absorbing means for this purpose. In this figure, the wrist pin **84** extends through a transverse opening **94** in the forming ram **14**, which opening is slightly elongated in the axial direction of the ram. Extending axially through the ram and communicating at one end with the wrist pin opening **94** is a bore **96** containing an orifice plate **98**. Orifice plate **98** defines a pair of chambers **100** and **102** located at opposite sides, respectively, of the orifice plate. These chambers communicate through a central orifice **104** in the plate **98**. The open end of chamber **102** is closed by a sealing disc **106** which is bolted to the end of the forming ram **14**, as shown. The ram chambers **100** and **102** contain pistons **108** and **110**, respectively. Formed in one end of the piston **108** is a cylindrically curved recess **112** for receiving the wrist pin **84**. Extending axially from the opposite end of the piston **108** is a tapered metering pin **114**. Piston **110** has a generally flat disc shape. Filling the chamber space between the pistons **108** and **110** is a liquid **116**. The chamber space defined between the sealing disc **106** and the piston **110** is filled with a gas **118** under high pressure.

The pressure of the gas **118** reacts on the piston **108** through the intervening piston **110** and liquid **116** and normally serves to firmly retain the wrist pin **84** in seating engagement with the adjacent wall of the wrist pin opening **94**. It is significant to note here that this wall provides a rigid seat against which the wrist pin is urged by the force transmitted to the wrist pin by the respective toggle **72** during retraction of the ram **14**. During the major portion of each forming stroke of the ram, the wrist pin remains in contact with this rigid seat on the ram. When the forming ram **14** reaches the end of its forming stroke it is abruptly arrested by the work forming impact, as explained earlier. The force exerted on the wrist pin **84**, by virtue of the momentum acquired by the pin and the toggle bars **74** during the forming stroke of the ram, tends to drive the wrist pin, and hence the ram piston **108**, forwardly in the ram chamber **100**. Forward movement of the piston **108** expels the liquid **116** through the orifice **104**, thereby driving the piston **110** forwardly against the gas pressure in the ram chamber **102**, and results in entry of the piston metering pin **114** into the orifice to progressively throttle liquid flow through the orfice. The wrist pin **84** is thereby gradually arrested without damage. FIGURE 3*b* illustrates a modified wrist pin shock absorbing means **120** wherein the fluid damping means of FIGURE 3*a* are replaced by a compression spring **122**. It will be understood that wrist pin shock absorbing means are embodied in both forming rams **14**.

Reference is now made to FIGURE 7 which illustrates the hydraulic circuitry of the forming machine described above. It will be readily observed in this figure that one pair of the ram actuators **46** is located at one side of a plane normal to the axes of the actuator cylinders **48** and containing the common axis of the ram cylinders **58** and the remaining pair of actuators is located at the opposite side of this plane. For convenience in the ensuing description, these actuator pairs are identified by the reference numerals **46*a*** and **46*b***, respectively. The hydraulic circuit of the forming machine includes a hydraulic pump **124** which receives hydraulic fluid from a reservoir **126** and discharges the fluid under pressure to the inlet **128*a*** of a four-way solenoid valve **128** having three outlets **128*b***, **128*c*** and **128*d***. Valve outlet **128*b*** is connected to the reservoir **126** through a return line **130**. Valve outlet **128*c*** is connected to the inner ends of the cylinders **48** of the ram actuators **46*a*** through a hydraulic line **132** and to the outer ends of the cylinders of the ram actuators **46*b*** through a hydraulic line **134**. Arranged in parallel in the hydraulic line **134** are an orifice **136** and a check valve **138**. Similarly, valve outlet **128*d*** is connected to the inner ends of the cylinders **48** of the ram actuators **46*b*** through a hydraulic line **140** and to the outer ends of the cylinders of the ram actuators **46*a*** through a hydraulic line **142**. Arranged in parallel in the hydraulic line **142** are an orifice **144** and a check valve **146**. Leading from the solenoid valve **128** are electrical leads **148** through which the valve may be energized for selective operation thereof to either of two positions. In one of these positions, the valve communicates the valve inlet **128*a*** to the valve outlet **128*c*** and the valve outlet **128*b*** to the return line **130**. In this valve position, then, the hydraulic circuit is conditioned for high pressure fluid flow from the valve **128** to the inner ends of the ram actuators **46*a*** and the outer ends of the ram actuators **46*b*** and for return flow of the hydraulic fluid from the outer ends of the ram actuators **46*a*** and the inner ends of the ram actuators **46*b*** to the reservoir **126**. In its second position, the valve **128** communicates the valve inlet **128*a*** to the valve outlet **128*d*** and the valve outlet **128*c*** to the return line **130**. In this valve position, the hydraulic circuit is conditioned for high pressure fluid flow from the valve to the inner ends of the ram actuators **46*b*** and the outer ends of the ram actuators **46*a*** and for return flow of hydraulic fluid from the inner ends of the ram actuators **46*a*** and the outer ends of the ram actuators **46*b*** to the reservoir **126**. It is evident at this point, therefore, that operation of the valve **128** to its first above described position, with the hydraulic pump **124** operating, effects simultaneous right hand extension of the piston rods **54** of the ram actuators **46*b*** and right hand retraction of the piston rods of the ram actuators **46*a***, as the actuators are viewed in FIGURE 7. Operation of the valve **128** to its second position effects simultaneous left hand extension of the piston rods of the ram actuators **46*a*** and left hand retraction of the piston rods of the ram actuators **46*b***. Each orifice **136** and **144** restricts hydraulic fluid flow to the outer ends of the actuators in such a way as to limit the rate of extension of the actuator piston rods. The check valves **138**, **146** open to permit unrestricted hydraulic fluid flow from the outer ends of the actuators, through the valve **128**, to the reservoir **126**, thus to permit rapid retraction of the actuator piston rods. In this regard, the hydraulic lines communicating the outer ends of the actuators to the reservoir preferably have a relatively large bore in order to accommodate unrestricted hydraulic fluid flow from the actuators to the reservoir.

Extending between the ports **66** in the outer ends of the ram cylinders **58** is a fluid conduit **150** which communicates the expansible pressure chambers **62** defined by these cylinders. Conduit **150** is also connected, through a valve **152**, to a source **154** of the working fluid **64** contained in the ram cylinders. The fluid conduit **150** has a relatively large bore and serves to constantly equalize the working fluid pressure in the expansible pressure chambers of the ram cylinders. This equalization of the working fluid pressure is highly desirable, for reasons which will appear presently.

A typical forming cycle of the forming machine **10** will now be described. In the normal condition of the machine, the forming rams **14** are retained in their extended forming positions of FIGURE 3 by the working fluid pressure in the expansible pressure chambers **62** and the knee joints **78** of the toggles **72** occupy one of their limiting positions. In the following discussion, it is assumed that the knee joints initially occupy the limiting positions illustrated in FIGURE 2. In this normal condition of the machine, the piston rods **54** of the ram actuators **46*a*** are fully retracted and the piston rods of the ram actuators **46*b*** are fully extended, as shown in FIGURE 2.

With the forming machine in this initial condition, a forming cycle of the machine is initiated by operating the valve **128** to communicate the valve inlet **128*a*** to the valve outlet **128*d*** and the valve outlet **128*c*** to the return line **130**. In this valve position, the ram actuators **46*a*** are pressurized to extend their respective piston rods **54** and the ram actuators **46*b*** are pressurized to retract their respective piston rods. Extension of the piston rods of the ram actuators **46*a*** drives the bearing forks **56** on these rods inwardly against the toggle knee joints **78**, thereby driving these joints inwardly toward their dead center positions of FIGURE 2*a*. This inward movement of the toggle knee joints causes the toggles **72** to exert outward forces on the forming rams **14** which retract these rams against the pressure of the working fluid within the expansible pressure chambers **62**. Outward retraction of the rams reduces the volume of the pressure chambers and thereby compresses the working fluid in the chambers. It is significant to note here that the toggles **72** produce a force multiplying action which amplifies the ram retraction force generated by the ram actuators **46*a***, thus permitting compression of the working fluid **64** within the expansible pressure chambers **62** to a high pressure level by retraction of the rams with relatively small low pressure ram actuators. It is further significant to note that the mechanical advantage of the toggles **72** increases sharply as the toggle knee joints **78** approach their dead center positions and the forming rams **14** approach their fully retracted positions. Accordingly, the mechanical advantage of the toggles enhances the retraction force amplification produced by these toggles and increases with the increase in working fluid pressure occasioned by approach of the forming rams **14** to their fully retracted positions. As a consequence, the pressure of the hydraulic fluid delivered to the ram actuators **46*a*** may remain relatively constant, at a relatively low pressure level, throughout the full stroke of these actuators. At some point during this retraction stroke of the forming rams **14**, a workpiece **30** is placed in the cavity of the lower forming die **28**.

Arrival of the forming rams **14** in their fully retracted positions of FIGURE 4 occurs simultaneously with movement of the toggle knee joints **78** to their dead center positions of FIGURE 2*a*. At this point, the forming machine **10** is conditioned for impulsion of the forming rams **14** through their forming strokes under the force of the compressed working fluid **64** in the expansible pressure chamber **62**. These forming srtokes of the rams are initiated by continued driving of the toggle knee joints **78** through their dead center positions to slightly over center positions. Movement of the knee joints to these over center positions simultaneously releases the forming rams for high velocity impulsion through their forming strokes by the compressed working fluid and results in snapping of the toggle knee joints to their left hand limiting positions of FIGURE 2*b*. In this regard, it will be recalled that check valves **138**, **146** embodied in the hydraulic circuit of the forming machine open to accommodate rapid retraction of the actuator piston rods. Accordingly, the piston rods of the ram actuators **46***b* are fully retracted when the forming rams **14** are thus released for movement through their forming strokes, whereby the latter actuators do not impede forming movement of the rams.

Arrival of the forming rams **14** at their extended forming positions of FIGURE 3 brings the forming dies **28** into percussive forming relation about the workpiece **30** currently positioned in the lower die. The workpiece is thereby subjected to a high intensity impact which deforms the material of the workpiece into conforming relation with the die cavity defined by the mating forming dies **28**. This completes one forming cycle of the forming machine. The next forming cycle of the machine is initiated by operating the valve **128** to extend the piston rods **54** of the ram actuators **46***b* and retract the piston rods of the ram actuators **46***a*. During this latter forming cycle, the toggle knee joints **78** are driven to the right from their limiting position of FIGURE 2*b*, through their dead center position of FIGURE 2*a*, to their limiting position of FIGURE 2, thus to initially retract the forming rams **14** against the working fluid pressure in the expensible pressure chamber **62** and compress this working fluid and thereafter release the forming rams for impulsion through their forming strokes under the force of the compressed working fluid in essentially the same way as described earlier in connection with the first forming cycle of the machine. At some point during the retraction strokes of the forming rams **14**, the previously formed workpiece is removed from its containing forming die **28** and a new workpiece is placed in the lower forming die. The following working or forming strokes of the forming rams **14** brings the forming dies **28** into percussive forming relation about this new workpiece, thereby deforming the latter into conforming relation with the die cavity, as before. A third forming cycle of the machine may then be effected by again driving the toggle knee joints **78** to the left from their limiting position of FIGURE 2 to their limiting position of FIGURE 2*b*.

In the foregoing discussion, it has been assumed that the upper frame structure **38** of the forming machine is oriented in the position of FIGURE 2, wherein the direction line **16** of ram movement is vertical. As noted earlier, however, the upper frame structure **38** is mounted on the frame base **32** for rotation to any other desired angular position. In this regard, for example, it is significant to note that in the position of the frame structure illustrated in FIGURE 2, gravity aids the travel of the upper forming ram **14** through its forming stroke and impedes the travel of the lower forming ram through its forming stroke. This creates an unbalanced force condition on the forming rams which may be undesirable in some forming applications. In these applications, the effect of gravity on the forming rams may be equalized by rotation of the upper frame structure **38** to its position of FIGURE 6, wherein the direction line **16** of ram movement is horizontal.

At this point, several unique and highly advantageous features of the forming machine **10** are obvious. One of these important features resides in the three fold function of the toggles **72**. Thus, these toggles serve, first, to transform the relatively small and generally constant output forces of the ram actuators **46***a*, **46***b* into large retraction forces on the forming rams **14** which increase sharply in magnitude with the increase in working fluid pressure within the expansible pressure chamber **62** occasioned by approach of the rams to their fully retracted positions of FIGURE 4. Secondly, the toggles effect precisely synchronized release of the forming rams for impulsion through their forming strokes under the force of the compressed working fluid in the pressure chamber in response to movement of the toggle knee joint **78** to their dead center positions. Thirdly, the toggles are effective to precisely synchronize movement of the rams through their forming strokes in such a way that the ram velocities are precisely equalized upon arrival of the rams at their forming positions of FIGURE 3. As noted earlier, the ram masses are also equalized. Accordingly, the forming rams arrive at their forming positions of FIGURE 3 with precisely matched kinetic energies. The rams, of course, are effectively isolated from the machine frame during their forming strokes. As a consequence, the total impact energy of the forming rams is absorbed totally by the workpiece and the rams themselves, and the rams are arrested at the conclusion of their forming strokes without any appreciable shock loading of the machine frame, components mounted on the frame, or the supporting floor through which the frame is attached. It is unnecessary, therefore, to mount the machine on a massive foundation, as required in many impact forming machines. The elimination of shock loading of the machine frame also results in longer service life, greater reliability of operation, and overall improved operating characteristics of the machine, and permits a relatively light weight low cost machine construction. These factors, in turn, permit the ram structure to be rotatably mounted on the machine frame, which is advantageous for the reasons discussed earlier.

The toggles **72** serve an additional, highly important safety function. Thus, since these toggles constrain the forming rams **14** to synchronized movement through their forming strokes, retardation or arresting of either ram in its foming stroke, due to jamming or binding of the ram in its cylinder **58**, will result either in corresponding retardation or arresting of the other ram or in freeing of the faulty ram. As a consequence, it is impossible for impact of the rams to occur under conditions other than those which yield accurately matched kinetic energies of the ram. As noted earlier, this is in distinct contrast to the existing forming machines wherein the forming rams are capable of independent movement. In these existing machines, then, either ram may continue in its high velocity forming movement even though the other ram should stall. Impact of the rams under these conditions, of course, would at least cause severe damage to the forming machine and might very likely cause disintegration of the machine, thus creating a serious safety hazard to the operating personnel. From what was said above, it is obvious that this potential safety hazard inherent in the existing forming machines is eliminated in the present forming machine.

It will be recalled that the toggle wrist pins **84** are capable of limited axial floating movement relative to the forming rams **14** and that the forward movement of these wrist pins, at impact, is gradually arrested by the wrist pin shock absorbing means (FIGURE 3*a* or FIGURE 3*b*) embodied in the forming rams. These shock absorbing means reduce the shock loading on the wrist pins at impact sufficiently to prevent bending or other damage to the wrist pins.

It will be recalled that the successive forming cycles of the forming machine under discussion are effected by driving the toggles **72** first in one direction and then in the opposite direction through their dead center positions. This unique toggle action of the machine adapts the latter for fast cycling operation and, therefore, for installation in a manufacturing production line. Thus, the machine may be operated as rapidly as the workpieces **30** can be fed to and removed from the machine. In this regard, it is obvious that the forming machine may be automated by providing a suitable workpiece feeding or indexing device for automatically feeding unformed workpieces to the forming dies of the machine in timed relation to the cycling operation of the machine.

It is evident at this point that the present forming machine may be used for various forming operations involving a wide range of forming ram impact energies. As noted earlier, however, the machine is particularly designed for high energy rate forming applications involving extremely high ram impact energies sufficient to cause plastic behavior of relatively hard work materials, such as alloy steels, and resulting plastic flow of these work materials into conforming relation with the forming die cavity. These high energy rate forming applications require compressed working fluid pressures on the order of 10,000 p.s.i. In order to attain these high working fluid pressures, it may be necessary to charge the expansible pressure chambers **62** of the machine with working fluid, from the working fluid source **154**, under an initial pressure which will yield the desired final high working fluid pressure when the working fluid in the pressure chambers is compressed by retraction of the forming rams **14**. It is well known, of course, that optimum high energy rate forming of a workpiece requires precise controlling of the impact energy delivered to the workpiece. Such precise energy control in the present high energy rate forming machine may be obtained by appropriate selection of the ram masses, regulation of the initial working fluid pressure in the expansible pressure chambers **62**, and/or appropriate selection of the various other parameters which determine the impact energy delivered to the workpiece by the forming rams **14**. Precise matching of the kinetic energies of the forming rams **14** at impact is particularly essential in high energy rate forming applications, not only to minimize or eliminate shock loading of the machine frame and its supporting floor, but also to assure application of precisely controlled impact forming energy to the workpiece. It is for this reason that the illustrated forming machine is provided with the conduit **150** for communicating the expansible pressure chambers **62** of the machine. This communication between the pressure chambers achieves precise equalization of the working fluid pressures in the chambers and, thereby, precise matching of the velocities, and hence kinetic energies, of the forming rams at impact. In this regard, it will be understood that the fluid conduit **150** is provided with a sufficiently large bore to assure free communication between the pressure chambers and, thereby, precise equalization of the chamber pressures throughout the entire working or forming strokes of the forming rams. It will be further understood that the forming rams are precisely matched to have, not only equal masses, as discussed earlier, but also equal effective areas exposed to the working fluid pressure in the pressure chambers.

Reference is now made to FIGURES 8 through 17 illustrating a modified and presently preferred embodiment of the present forming machine. The modified forming machine **200** is basically similar to the forming machine described above in that the modified machine embodies a frame **202** mounting a pair of forming rams **204** for movement along a common direction line **206**. Associated with these forming rams are retraction means **208** for driving the rams from their extended forming positions of FIGURES 8, 9, 12 and 17 to their retracted positions of FIGURE 16 and ram driving means **210** for driving or impelling the rams from the retracted positions to their forming positions. As in the previous form of the invention, the ram retraction means **208** embody force multiplying or amplifying toggle linkage means **212** for retracting the forming rams **204** against working fluid pressure in such a way that the retraction forces active on the rams increases sharply with the increase in working fluid pressure occasioned by approach of the rams to their fully retracted positions, for affecting precisely synchronized release of the forming rams for impulsion through their forming strokes by the compressed working fluid, and for effecting precisely synchronized movement of the forming rams through their forming strokes, thus to achieve precise matching or balancing of the kinetic energies of the rams at impact. This precise matching of the ram energies at impact minimizes or eliminates high rate impact loading of the machine frame and its supporting floor and accommodates a relatively light weight low cost machine construction, thus eliminating the necessity of a supporting foundation for the machine and permitting rotatable mounting of the forming ram structure, as in the earlier embodiment of the invention.

Referring now in greater detail to the modified forming machine **200**, the machine frame **202** includes a supporting base **214** having upstanding plate like arms **216**, and an upper frame structure **218** which is disposed between and rotatably supported on the upper ends of the base arms **216**. The upper frame structure **218** includes a pair of spaced, generally rectangular frame plates **220** having arm like formations **222** projecting laterally from their longitudinal edges, intermediate the ends of the plates. Disposed between and welded or otherwise rigidly joined to the frame plates **220**, adjacent the ends of these plates, are a pair of frame blocks **224**. The longitudinal axes of the frame plates **220** parallel the direction line **206** of movement of the forming rams **204**. The frame blocks **224** are centered on and are disposed in planes normal to this direction line. Frame blocks **224** are joined by a pair of guide rods **226** having reduced, shouldered ends which extend through openings in corresponding diagonally opposite corners of the blocks. Nuts **228** are threaded on the ends of these guide rods to firmly secure the rods to the frame blocks **224**. Guide rods **226** parallel the direction line **206** of forming ram movement.

Forming rams **204** comprise coaxial cylinders **230** having inner confronting working ends **232** closed by end walls **234**. The opposite, outer ends of the ram cylinders **230** are open. Bolted or otherwise firmly attached to the inner end wall **234** of each ram cylinder **230** is a slide **236**. The outer end of each ram cylinder extends through a central opening in a second slide **238** which is welded or otherwise rigidly joined to the respective cylinder. Slides **236** and **238** have openings in diagonally opposite corners thereof slidably receiving the guide rods **226**. It is evident at this point, therefore, that the guide rods **226** and the slides **236**, **238** slidably support the ram cylinders **230** on the upper frame structure **218** for movement along the direction line **206**.

Ram retraction means **208** comprise, in addition to the toggle linkage means **212**, a pair of hydraulic or pneumatic actuators **240** including coaxial cylinders **242**, the common axis of which extends normal to the direction line **206** of the forming ram movement. The inner ends of the actuator cylinders **242** are located between the frame plate arm formations **222** and have external rectangular shoulders **244** which seat flush against and are welded or otherwise rigidly joined to the inner surfaces of these formations. Slidable within each actuator cylinder **242** is a piston having a rod **246** which extends from the inner end of the respective cylinder. A bearing fork **248** is rigidly joined to the outer end of each actuator piston rod **246**. Each bearing fork **248** has spaced, inwardly directed fork arms **250**.

Rigidly mounted on the inner surfaces of the frame plates **220**, just inwardly of each ram actuator **240**, are a pair of guides **252**. These guides have aligned guide slots or tracks **254** disposed in a common plane normal to the frame plates **220** and containing the axis of the actuator cylinders **242**. The longitudinal sides of each actuator bearing fork **248** fit slidably within the adjacent guide slots **254**. Accordingly, the bearing forks slide back and forth along and are restrained against rotation about the axis of the actuator cylinders **242** by the guides **252** during extension and retraction of the actuator piston rods **246**.

The toggle linkage means **212** of the forming machine under discussion comprise a pair of toggles **256**. Each toggle **256** includes a pair of toggle bars **258**, **260** which are pivotally joined at their inner ends by a knee joint **262**. The toggle knee joints **262** are disposed between the arms **250** of the actuator bearing forks **248**, respectively, and include knee shafts **264** which are engaged by recessed end faces of the adjacent fork arms **250**, in the manner shown best in FIGURE 15. Referring to FIGURE 14, it will be observed that the bearing fork guides **252** are longitudinally grooved to receive the projecting ends of the toggle knee shafts **264**. The opposite or outer ends of the toggle bars **258**, **260** are pivotally attached to a pair of thrust plates **266** which are slidably supported on the guide rods **226**. These thrust plates are located between the slides **236**, **238** for the ram cylinders **230**, respectively. Each thrust plate has a central opening slidably receiving the adjacent ram cylinder. Each ram cylinder has an external, inwardly facing annular shoulder **268** against which the adjacent thrust plate **266** is adapted to seat to transmit an outward retraction force on the respective cylinder.

At this point, it is evident that inward extension of the actuator piston rods **246** is effective to drive the toggle knee joints **262** inwardly toward their positions of FIGURE 16, wherein the knee joints are located slightly beyond their dead center positions. The knee joint positions illustrated in FIGURE 16 are hereinafter referred to as their over center positions. It is significant to note here that the inner ram cylinder slides **236** and the thrust plates **266** are notched to accommodate movement of the toggle bars **258**, **260** to their over center positions of FIGURE 16. It is obvious that this inward movement of the toggle knee joints **262** to their over center positions is effective to initially drive the thrust plates **266** outwardly into seating engagement with the ram cylinder thrust shoulders **268** and thereafter to drive the thrust plates and ram cylinders outwardly in unison to the retracted positions of the cylinders illustrated in FIGURE 16. As in the previous form of the invention, the retraction forces exerted on the ram cylinders **230** by the toggles **256** increase sharply as the toggle knee joints **262** approach their dead center positions and the ram cylinders **230** approach their fully retracted positions. The toggles **256** are also effective, obviously, to synchronize movement of the ram cylinders **230** from their retracted positions to their forming positions of FIGURES 9 and 17.

The forming ram driving or impulsion means **210** of the forming machine **200** comprise pistons **270** which are rigidly joined to the fixed frame blocks **224** and fit slidably within the ram cylinders **230**. The ram cylinders and pistons cooperatively define expansible pressure chambers **272** containing a working fluid, such as any one of those fluids mentioned earlier. As in the previous form of the invention, the working fluid in the pressure chambers **272** is compressed by outward retraction of the forming ram cylinders **230**.

It is now evident that the forming rams **204** comprise the ram cylinders **230** and the ram cylinder slides **236**, **238**. During operation of the forming machine, the work forming dies **274** are mounted on the inner confronting faces of the inner cylinder slides **236**. As in the previous form of the invention, these dies are movable into percussive work forming relation about a workpiece **276** by inward impulsion of the forming rams **204** through their forming strokes under the force of the compressed working fluid in the expansible pressure chambers **272**. During these inward forming strokes of the forming rams, the ram thrust plates **266** acquire substantial momentum or kinetic energy which tends to cause continued forward or inward movement of these plates after impact of the forming dies with the workpiece. For this reason, the forming machine is equipped with shock absorbing means **278** for arresting the thrust plates **266** with minimal shock loading. Various forms of shock absorbing means may be employed for this purpose. The illustrated shock absorbing means comprise pistons **280** which are rigidly secured to the inner forming ram slides **236** and fit slidably within piston bores **282** in the forming ram thrust plates **266**. These piston bores communicate with their adjacent forming ram pressure chambers **272** through restricted bleed passages **284** in the respective forming rams and additional restricted bleed passages in the pistons **280**. It is evident, therefore, that during operation of the forming machine, working fluid will bleed from the pressure chambers **272** into the piston bores **282** and will impede forward or inward movement of the thrust plates **266** relative to the pistons **280**, thus to gradually arrest the thrust plates following impact of the forming dies **274** with the workpiece **276**.

The forming machine under discussion is equipped with means **286** for ejecting the formed workpiece from its containing forming die cavity. Ejecting means **286** comprise a pair of cylinders **288** which are rigidly secured to the outer surfaces of the fixed frame blocks **224** in coaxial alignment with the forming ram cylinders **230** and pistons **270**. Slidable in each ejector cylinder **288** is a piston **290** having a rod **292** which extends through the adjacent frame block **224** and piston **270** into a bearing sleeve **294**, which extends through and is fixed to the inner end of the adjacent forming ram **204** and slides within a bore in the adjacent ram piston **270**. The ejector rods **292** and the bearing sleeves **294** are sealed, as shown, to prevent the fluid leakage. The ejector rods **292** are axially movable between their retracted positions of FIGURE 12, wherein the inner ends of the rods are retracted into the bearing sleeves **294**, and their extended positions of FIGURE 16, wherein the inner ends of the rods project beyond the inner ends of the forming rams **204** and through the forming dies **274**. At the conclusion of each forming cycle, the ejector rod associated with the forming die containing the finished work part is extended to eject the part.

It will be recalled that the toggle knee joints **262** are adapted to be driven, by the ram actuators **240**, from their limiting positions of FIGURE 12 to their over center positions of FIGURE 16 to affect retraction of the forming rams **204** against the working fluid pressure within the pressure chambers **272**. Movement of the toggles beyond these over center positions is limited by engagement of the toggle bars **258**, **260** with the bottom walls of the toggle bar clearance slots or notches in the inner forming ram slides **236**. It is obvious that the toggles **256**, when in these over center positions, are effective to retain the forming rams **204** in their retracted positions of FIGURE 16 against the force of the compressed working fluid in the pressure chambers **272**. Means **296** are provided for driving the toggles **256** from their over center positions back through and slightly beyond their dead center positions, thus to release the forming rams **204** for impulsion through their forming strokes under the force of the compressed working fluid. The illustrated toggle release means **296** comprise a pair of toggle release levers **298** pivotally mounted on the machine frame **202**. These toggle release levers have tapered camming arms **300** which are engageable with projecting lugs **302** rigid on the toggle bars **258**. When the toggles **256** occupy their over center positions of FIGURE 16, the toggle bar lugs **302** seat against the arms **300** of the toggle release levers **298**, as shown. It is evident at this point that upward rotation of the toggle release levers **298**, as viewed in FIGURE 16, is effective to urge the tapered lever arms **300** against the toggle bar lugs **302** and thereby drive the toggles **256** outwardly from their illustrated over center positions through their dead center positions, thus to release the forming rams **204** for impulsion through their forming strokes. Such upward rotation of the toggle release levers **298** is effected by lever actuating means **304** on the machine frame. These lever actuating means may comprise solenoids or fluid pressure actuators, for example. Preferably, means are provided for preventing downward rotation of the levers **298** beyond the position of FIGURE 16, whereby abutment of the toggle bar lugs **302** against the lever arms **300** aids in preventing movement of the toggles **256** beyond their over center positions. Attention is directed to the fact that the toggle bars **258** are longitudinally slotted to clear the toggle release levers **298** and their actuating means **304** during movement of the toggles from their over center positions of FIGURE 16 to their limiting positions of FIGURE 12.

Reference is now made to FIGURE 17 which illustrates the hydraulic system of the modified forming machine. Since this hydraulic system is believed to be self evident from the drawings, it will be described only in general terms. Suffice it to say that the hydraulic system includes a first hydraulic circuit **306** for effecting simultaneous extension and retraction of the piston rods **246** of the forming ram actuators **240**, hydraulic circuits **308** and **310** for selectively extending and retracting the work piece ejector rods **292**, and a hydraulic circuit **312** for operating the toggle release lever actuating means **304**, which are shown in FIGURE 17 to comprise hydraulic actuators. Reference numeral **314** in FIGURE 17 designates a working fluid supply system for charging the expansible pressure chambers **272** of the forming machine with working fluid. The working fluid supply system includes a pressurized source **316** of the working fluid and solenoid valves **318** for selectively communicating the fluid supply **316** to the pressure chambers **272** through fluid lines **320** which extend axially through the stationary forming ram pistons **270**. An adjustable fluid pressure regulator **322** is placed between the fluid supply **316** and the pressure chambers, as shown, to permit selective regulation of the pressure of the working fluid delivered to the pressure chambers, thus to permit regulation of the initial working fluid pressure in the chambers and hence the final pressure to which the working fluid is compressed by retraction of the forming rams **204**. The pressure chambers **272** freely communicate through a relatively large fluid line **324**, as in the previous form of the invention, thus to equalize the working fluid pressures in the two pressure chambers, for the reasons mentioned earlier.

The operation of the modified forming machine is believed to be obvious from the foregoing description. Thus, a forming cycle of the machine is initiated by pressurizing the ram actuators **240** in directions to drive the toggles **256** to their over center positions of FIGURE 16 and thereby retract the forming rams **204** against the pressure of the working fluid within the expansible pressure chambers **272**. This retraction of the forming rams is effective to compress the working fluid in the pressure chambers to the high pressure level required for forming operation of the machine. Movement of the toggles **256** to their over center positions of FIGURE 16 effectively latches the forming rams **204** in their retracted positions against the force of the compressed working fluid. At this point, a workpiece or billet **276** is placed in the cavity of the lower forming die **274**. The ram actuators **240** are then pressurized in directions to retract their piston rods **246** and their bearing forks **248**, thus to free the toggles **256** for unrestricted outward movement and thereby condition the machine for subsequent inward forming strokes of the forming rams **240**.

The forming strokes of the forming rams **204** are initiated by operating the actuating means **304** for the toggle release levers **298**, thus to drive these levers upwardly in FIGURE 16 and thereby drive the toggles **256** outwardly from their over center positions of the latter figure through and slightly beyond their dead center positions. The forming rams **204** are thereby simultaneously released for inward impulsion through their forming strokes by the compressed working fluid in the expansible pressure chambers **272**. At the conclusion of these forming strokes, the forming dies **274** enter into percussive forming relation about the workpiece **276**, thus to deform the workpiece into conforming relation with the forming die cavity, in the manner explained earlier. The forming ram actuators **240** are then again pressurized to retract the rams, after which the formed workpiece is ejected from its containing forming die by pressurizing the corresponding ejector cylinder **288** to extend the corresponding ejector rod **292**, as shown in FIGURE 16.

It is now obvious that the modified forming machine possesses the same inherent unique features and advantages as the forming machine described earlier. Accordingly, these features and advantages need not be repeated. It should be noted, however, that the modified forming machine of FIGURES 8 through 17 is superior to the earlier forming machine of FIGURES 1 through 7 for the reason that the forming rams **204** may be latched in their retracted positions, thus to facilitate placement of the unformed workpiece end and removal of the formed workpiece from the machine. It will be understood, of course, that the modified forming machine, like the earlier forming machine, is susceptible of a variety of forming applications but is particularly designed for high energy rate forming applications.

It is obvious, therefore, that the invention herein described and illustrated is fully capable of attaining the several objects and advantages preliminarily set forth.

Although specific embodiments of the present invention have been illustrated and described herein, it will be understood that the same are merely exemplary of presently preferred embodiments capable of attaining the objects and advantages hereinbefore mentioned, and that the invention is not limited thereto; variations will be readily apparent to those versed in the art, and the invention is entitled to the broadest interpretation within the terms of the appended claims.

I claim:

1. An impact forming machine comprising:

a frame,

a pair of forming rams having confronting working ends,

means mounting said rams on said frame for movement along a common direction line relative to said frame between remote retracted positions and proximate forming positions,

toggle linkage means positively connecting said rams for effecting precisely synchronized movement of said rams in unison between said positions comprising a toggle including a pair of toggle bars having their adjacent ends pivotally connected by a knee joint and their remote ends pivotally connected to said rams, respectively, in such manner that said knee joint undergoes movement along a second direction line transverse to said first mentioned direction line during said synchronized ram movement between said positions, and coacting guide means on said frame and toggle for constraining said knee joint to movement along said second direction line,

said knee joint having a dead center position along said second direction line and said rams being movable to said retracted positions thereof in response to movement of said knee joint to said dead center position,

power means operative between said frame and toggle for driving said knee joint to said dead center position, thereby to drive said rams to their retracted positions, and thereafter driving said knee joint from said dead center position and releasing said toggle for unrestricted movement of said knee joint along said second direction line, thereby to release said rams for movement to said forming positions thereof, and

means for driving said rams to their forming positions following said release thereof.

2. An impact forming machine comprising:

a frame,

a pair of forming rams having confronting working ends,

means mounting said rams on said frame for movement along a common direction line relative to said frame between remote retracted positions and proximate forming positions,

mechanical linkage means positively connecting said rams for effecting precisely synchronized movement of said rams in unison between said positions,
yieldable ram driving means for impelling said rams to said forming positions thereof, and
power means on said frame for driving said rams to their retracted positions against the force of said ram driving means and then releasing said rams for synchronized movement to their forming positions under the force of said driving means and the synchronizing action of said linkage means.

3. An impact forming machine according to claim 2 wherein:
said linkage means are movable from a first position to a second position to drive said rams from their forming positions to their retracted positions and said linkage means are movable from said second position to another position to release said rams for movement from their retracted positions to their forming positions, and
said linkage means are operatively connected between said power means and said rams in such manner that said power means are effective to drive said linkage means from said first position to said second position and thereafter release said linkage means for movement to said other position thereof.

4. An impact forming machine comprising:
a frame,
a pair of forming rams having confronting working ends,
means mounting said rams on said frame for movement along a common direction line relative to said frame between remote retracted positions and proximate forming positions,
mechanical linkage means positively connecting said rams for effecting precisely synchronized movement of said rams in unison between said positions,
yieldable drive means for impelling said forming rams to their forming positions,
said linkage means comprising a toggle including a pair of toggle bars having their adjacent ends pivotally connected by a knee joint and their remote ends pivotally connected to said rams, respectively, in such manner that said knee joint undergoes movement along a second direction line transverse to said first mentioned direction line during said synchronized ram movement between said positions, and coacting guide means on said frame and toggle for constraining said knee joint to movement along said second direction line,
said knee joint being movable through a dead center position along said second direction line and said rams being movable to their retracted positions in response to movement of said knee joint to said dead center position,
power means operative between said frame and said toggle for driving said knee joint to said dead center position, thereby to drive said rams to their retracted positions against the force of said ram driving means and thereafter driving said knee joint from said dead center position and releasing said toggle for unrestricted movement of said knee joint along said second direction line, thereby to release said rams for movement to their forming positions under the force of said ram driving means.

5. An impact forming machine according to claim 4 wherein:
said knee joint is movable along said second direction line from a first limiting position through said dead center position to a second limiting position to initially drive said rams from their forming positions to their retracted positions and then release said rams for movement from their retracted positions to their forming positions, and

said power means are effective to drive said knee joint from said first limiting position to a position slightly beyond said dead center position and then release said toggle for unrestricted movement of said knee joint to said second limiting position.

6. An impact forming machine according to claim 5 including:
additional power means operative between said frame and toggle for driving said knee joint from said second limiting position to a position slightly beyond said dead center position and then releasing said toggle for unrestrained movement of said knee joint to said first limiting position, and
means for operating said power means alternately.

7. An impact forming machine comprising:
a frame,
a pair of forming rams having confronting working ends,
means mounting said rams on said frame for movement along a common direction line relative to said frame between remote retracted positions and proximate forming positions,
mechanical linkage means positively connecting said rams for effecting precisely synchronized movement of said rams in unison between said positions,
yieldable drive means for impelling said rams to their forming positions,
said linkage means comprising a toggle including a pair of toggle bars having their adjacent ends pivotally connected by a knee joint and their remote ends pivotally connected to said rams, respectively, in such manner that said knee joint undergoes movement along a second direction line transverse to said first mentioned direction line during said synchronized ram movement between said positions, and coacting guide means on said frame and toggle for constraining said knee joint to movement along said second direction line,
said knee joint occupying a limiting position along said second direction line when said rams occupy their forming positions and said knee joint being movable along said second direction line from said limiting position through a dead center position to a slightly over center position to drive said rams to their retracted positions,
power means operative between said frame and toggle for driving said knee joint from said limiting position to said over center position, thereby to drive said rams to their retracted positions against the force of said ram driving means,
means for releasably retaining said knee joint in said over center position, thereby to releasably retain said rams in their retracted positions against the force of said ram driving means, and
toggle release means operative between said frame and toggle for driving said knee joint from said over center position through said dead center position and then releasing said toggle for unrestrained movement of said knee joint to said limiting position, thereby to release said rams for impulsion to their forming positions under the force of said said ram driving means.

8. An impact forming machine comprising:
a frame,
a pair of forming rams having confronting working ends,
means mounting said rams on said frame for movement along a common direction line relative to said frame between remote retracted positions and proximate forming positions,
toggle linkage means positively connecting said rams for effecting precisely synchronized movement of said rams in unison between said positions,
means cooperating with said rams to define expansible pressure chambers containing compressible working

fluid for impelling said rams from their retracted positions to their forming positions, and means connected to said toggle linkage means for driving said rams to their retracted positions to compress said working fluid and then rapidly releasing said rams for impulsion to their forming positions under the pressure of the working fluid in said pressure chambers.

9. An impact forming machine comprising:
a frame,
a forming ram mounted on said frame for movement between a retracted position and a forming position, yieldable ram driving means for impelling said ram to its forming position,
a toggle operatively connected between said frame and ram and including a knee joint which is movable from a limiting position to a dead center position to drive said ram from said forming position to said retracted position against the force of said ram driving means, and
power means operative between said frame and toggle for driving said knee joint from said limiting position to said dead center position and then releasing said toggle for unrestrained movement of said knee joint from said dead center position, thereby to release said ram for impulsion to its forming position under the force of said ram driving means.

10. An impact forming machine according to claim 9 wherein:
said knee joint is movable from said limiting position through said dead center position to a second limiting position to effect initial driving of said ram to its retracted position and subsequent release of said ram for impulsion to its forming position, and
said power means is effective to drive said knee joint from said first mentioned limiting position through and slightly beyond said dead center position and then release said toggle for unrestrained movement of said knee joint to said second limiting position.

11. An impact forming machine according to claim 9 wherein:
said knee joint is movable from said limiting position through said dead center position to an over center position slightly beyond said dead center position and from said over center position back through said dead center position to said limiting position to initially drive said ram to its retracted position and thereafter release said ram for impulsion to its forming position,
said power means is effective to drive said knee joint from said limiting position to said over center position,
means for releasably retaining said knee joint in its over center position, thereby to retain said ram in its retracted position against the force of said ram driving means, and
toggle release means operative between said frame and toggle for driving said knee joint from said over center position through and slightly beyond said dead center position and then releasing said toggle for unrestrained movement of said knee joint to said limiting position, thereby to release said ram for impulsion to its forming position under the force of said ram driving means.

12. An impact forming machine according to claim 9 wherein:
said toggle includes a toggle bar and means including a wrist pin extending transversely through said ram for pivotally connecting said toggle bar to said ram, said wrist pin being capable of limited floating movement axially of said ram, and
shock absorbing means operative between said ram and wrist pin for yieldably resisting movement of said wrist pin axially of said ram in the direction of said forming position of the ram.

13. An impact forming machine according to claim 9 wherein:
said toggle includes a toggle bar, a thrust plate mounted for limited axial movement on said ram, and means pivotally connecting said toggle bar to said thrust plate, whereby said toggle is effective to transmit axial thrust to said ram through said thrust plate, and
shock absorbing means operative between said ram and thrust plate for yieldably resisting axial movement of said plate relative to said ram in the direction of the forming position of said ram.

14. An impact forming machine comprising:
a frame,
a pair of forming rams having working ends,
means mounting said rams on said frame for relative movement along a common direction line relative to said frame between remote retracted positions and proximate forming positions,
ram driving means for impelling said rams from their retracted positions to their forming positions, and
quick release toggle linkage means operatively connected between said rams and movable to and from dead center position for retaining said rams in their retracted positions against the force of said ram driving means and rapidly simultaneously releasing said rams for impulsion to their forming positions under the force of said ram driving means.

15. An impact forming machine comprising:
a frame,
a pair of forming rams having working ends,
means mounting said rams on said frame for relative movement along a common direction line relative to said frame between remote retracted positions and proximate forming positions,
ram driving means for impelling said rams from their retracted positions to their forming positions,
quick release mechanical linkage means operatively connected between said rams for retaining said rams in their retracted positions against the force of said ram driving means and rapidly simultaneously releasing said rams for impulsion to their forming positions under the force of said ram driving means,
said linkage means comprising a toggle including a pair of toggle bars having their adjacent ends pivotally joined by a knee joint and pivotally connected at their outer ends to said rams, respectively, in such manner that said knee joint is movable from a first position to a second position to effect driving of said rams from their forming positions to their retracted positions against the force of said ram driving means and said knee joint is movable from said second position to simultaneously release said rams for impulsion to their forming positions under the force of said ram driving means, and
power means operative between said frame and toggle for driving said knee joint from said first position to said second position, thereby to retract said rams, and thereafter releasing said toggle for unrestrained movement of said knee joint from said second position, thereby to release said rams for impulsion to their forming positions.

16. An impact forming machine comprising:
a frame including a lower base portion and an upper frame structure pivotally mounted on said base portion for turning on a normally horizontal axis,
a pair of forming rams mounted on said frame structure for movement relative to said frame structure along a common direction line normal to said axis,
said rams being movable along said direction line between remote retracted positions and proximate forming positions,
means for driving said rams from their forming positions to their retracted positions,

means for impelling said rams from their retracted positions to their forming positions in such manner that said rams arrive at their forming positions with substantially equal kinetic energies, and

said frame structure being rotatable relative to said base portion to selectively locate said direction line of ram movement in any desired angular attitude.

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