serve to point the way toward effective designs utilizing this principle.

Another type of pressure-generating equipment that might possibly be applied to metal forming is the multiple-anvil press introduced by H. T. Hall.[8] This apparatus, which was used in the early work to synthesize diamond, is used extensively today in materials investigations, particularly those in which high temperatures as well as high pressures are required. As shown in Figure 4, the equipment consists of four or more truncated pyramidal anvils that can be driven together by hydraulic cylinders to enclose and apply pressure to a central volume in the shape of a tetrahedron or cube. Initially, the anvils are separated by a pyrophyllite gasket shaped to line the closure space and enclose the test sample. Pyrophyllite has the ideal properties of becoming compressible and ductile under high pressure and also of having an extremely high coefficient of friction—the latter property allowing it to maintain its sealing position without extruding outward. In addition, pyrophyllite is machinable and an excellent insulator of heat.

Very similar to the multiple-anvil press is the General Electric "belt apparatus", which consists of two conical high-pressure pistons surrounded by a cylinder having a matched taper at its ends.[9] With this design and the use of pyrophyllite gaskets, the action of the pistons entering from either end can subject the enclosed cylindrical volume to enormous pressure. In fact, both the press and the belt apparatus are capable of generating pressures in the neighborhood of 2,000,000 psi; however, the fact that expensive gasketing is employed and discarded after each operation makes it difficult to find appropriate metal-forming applications.

Fortunately, most metals enjoy a great increase in ductility without being subjected to more than 200,000 psi; in fact, the more commonly formed materials such as copper, brass, and aluminum reach maximum ductility at pressures below 100,000 psi. For this reason the shrunk-ring cylinder, despite its limitations, is by far the most widely used for metal forming.

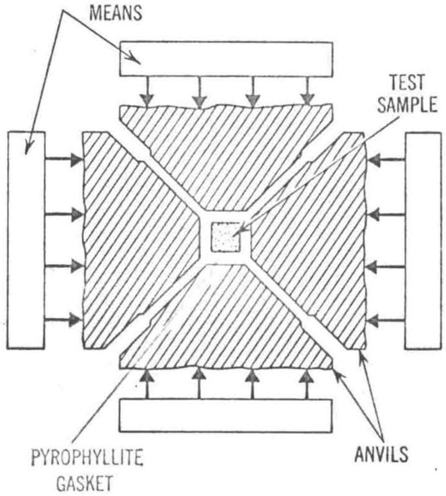


Figure 4. Multiple-anvil press first used to synthesize diamond.

## A NEW PRESSURE VESSEL

To form the more difficult materials it is desirable, nevertheless, to have a vessel capable of cycling repeatedly up to 500,000 psi. Such a vessel has recently been developed at the Western Electric Engineering Research Center. Incorporating many of the outstanding features of the higher-pressure equipments, the new vessel can also be as easily loaded and unloaded as the simple piston-cylinder device.

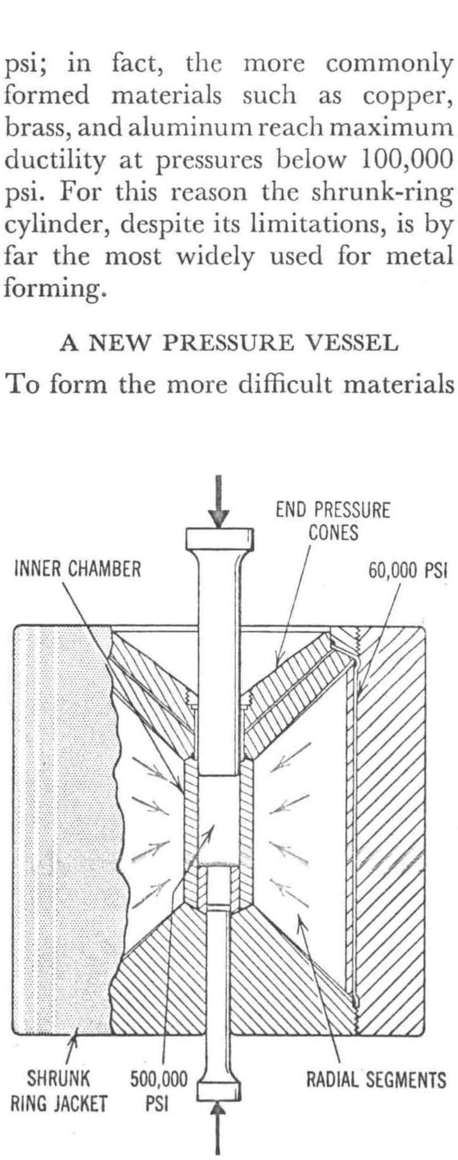


Figure 5. A self-sealing high-pressure vessel capable of repeated cycling.

As shown in Figure 5, the new pressure vessel is primarily a relatively thin-walled cylinder made of hard material. The particular cylinder diagrammed has a two-inch bore and a seven-inch working length. To support this chamber a number of radial segments are mounted to its outer surface and held in place by a thin press-fit ring. The whole assembly in turn is enclosed by a shrunk-ring jacket that will contain a pressure of 60,000 psi without fatigue. In addition, to support the ends of the chamber and prevent high fluid pressure from "pinching off" the chamber wall conical members are provided at the top and bottom. The lower one is threaded into the outer jacket, and the upper one is made to act as a hydraulic piston. Finally, passageways are drilled through the upper cone to allow fluid to pass from the region just above the high-pressure chamber out to the large jacket.

In operation of this pressure vessel, the inner chamber, into which the part or test sample is placed, is filled with fluid, and a hydraulic press is used to force the upper piston into the top of the chamber. As the action of the piston increases the pressure of the fluid, the chamber tends to expand and thereby permit fluid to leak past the close-fitting piston. This fluid flows through the special passageways out to the containing jacket, where the fluid applies pressure to the outside of the radial segments and to the top of the conical end support. The segments and the end support in turn transmit the pressure inwards to the inner chamber, which closes down on the piston to stop further leakage.

Since the supporting fluid pressure in this design acts over a large area while the high-pressure fluid within

[8] Alexander Zeitlin, "Equipment for Ultrahigh Pressures," *Mechanical Engineering*, October 1961, pp. 37-43.

[9] H. T. Hall, "Ultrahigh Pressure, High-Temperature Apparatus, The Belt", *Review of Scientific Instruments*, Vol. XXXI, No. 2 (February 1960), pp. 125-131.