High-Pressure Seals and the Invention of the Hydraulic Press

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Two previous papers[1,2] have dealt with the O-ring and its applications. This seal is best suited to vacuum technology, where the maximum difference in pressure is a mere 15 pounds per square inch (psi), although it will withstand higher pressures in well-designed static situations. High pressures, such as the hundreds of psi now used in moving hydraulic machinery, are better retained by 'U' and 'chevron' packings employing the principle of a self-adjusting 'lip-seal'.

Hydrostatic Pressure

As early as 1586 Simon Stevin[3] had grasped that, in a body of water at rest, the hydrostatic pressure varied directly with depth and acted equally in all directions. The implications of the latter statement were seen by Blaise Pascal, who in 1647 designed[4] a 'machine for multiplying forces' (Fig.1). The larger piston was 100x the area of the smaller, so if the latter was loaded with unit weight then the large piston would support 100 units, although rising through only 1/100 of any distance through which the small piston was depressed. Pascal's machine lacked any special seals on its sliding pistons, so was suited only to visual demonstrations involving low pressures. Perhaps this is why he never saw it as a practical apparatus to compete with the screw presses widely used for grapes, olives, etc.

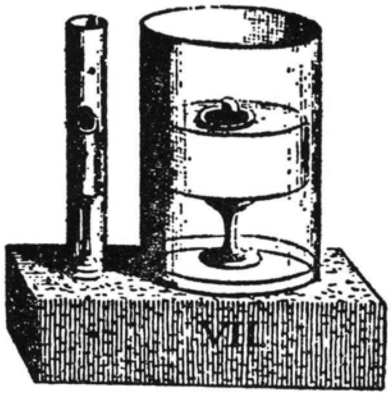

Fig.1 *Pascal's 'machine for multiplying forces', 1647.*

The Hydraulic Press

Practical realisation of the hydraulic press must be credited to the wide-ranging genius of Joseph Bramah. Whether he was aware of the work of Pascal we shall never know, but in 1795 he patented[5] a machine for multiplying the effort exerted on a simple force pump. It was connected to a cylinder and piston of large diameter, employing Pascal's principle to compress anything placed between this piston and a stout timber frame secured by undercut tenons (Fig. 2).

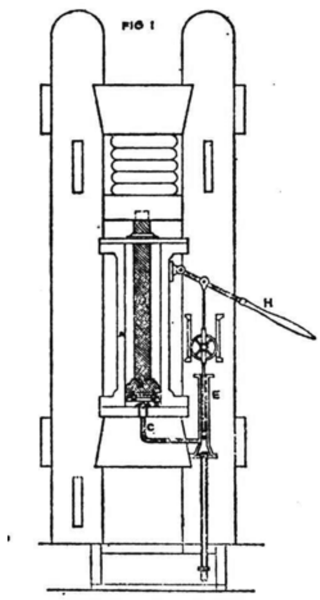

Fig. 2 *Illustration from Joseph Bramah's patent for a hydraulic press, 1795.*

Bramah calculated a force of 2000 tons could be exerted upon a 12" diameter ram by a lever-driven manual pump terminating in a ¼" diameter piston. This figure is far in excess of the strength of the materials involved, but even 20 tons would be superior to the screw-presses of the time. Bramah does not specify the working fluid, but would have been well aware that the corrosion associated with water made a cheap vegetable oil (e.g. the rape seed or colza oil used in lamps) preferable.

The main problem that Bramah had to solve to produce a working hydraulic machine was completely preventing leakage of high-pressure fluid. Liquids are almost incompressible, so leakage of only a few drops would dramatically lower the pressure within the chambers. Contemporary steam engines had a packing of greasy hemp wound around their pistons, while the rods emerging from double-acting cylinders benefitted by compressing similar packing with a bolted-down cover plate. But pressures were comparatively low, and loss of a little steam was both tolerable and expected. Bramah may well have tried such a 'stuffing box' with its resulting packing of rectangular section, but would soon have discovered that to produce a leak-free sliding seal required such extreme compression that a raised ram would not readily descend!

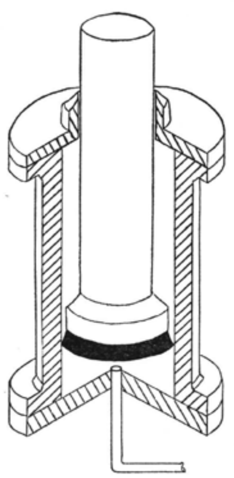

Fig. 3 *Hydraulic ram sealed with a cup washer at the bottom. (After McNeil[8])*

The solution was before him in the 'cup-leather' used from ancient times in ordinary water pumps, and now represented in the bicycle pump. Positioned at the end of the piston rod with its concave side towards the pressure, this simple but clever device is expanded by any significant pressure until its lip and sides are in close contact with the surrounding walls. The greater the pressure to be retained, the harder the leather is pressed outwards: the seal is largely self-adjusting. Bramah's 1795 patent appears to show cup washers on the ends of both pump and ram: both should have worked well enough provided that the bores were straight and true, and machined to a fine finish approaching a polish (Fig.3). This is not too difficult with the small-bore pump, but the large cylinder is a different matter. It is best cast as a single block, with the closed end integral with the walls. Boring it out in a lathe would therefore require an overhanging tool of considerable length, with consequent problems of chatter and non-uniform bore. In contrast, a plain cylindrical ram can be turned between centres, where it is easily accessible for measuring and fine finishing.

The U-leather

By 1813 we find that a ram of this nature is in use, being sealed *at the top* with an annulus of U-shaped leather (Fig. 4). This would behave similarly to the cup washer, pressure within the interior pressing it outwards against ram and retaining walls in a self-adjusting manner. A strong cover plate, bored to a sliding fit for the ram, was still required to prevent its upward extrusion. Relaxation of the pressure would allow the ram to descend under its own weight. The one-piece cylinder casting needs machining only at the top: the bore could be left 'as

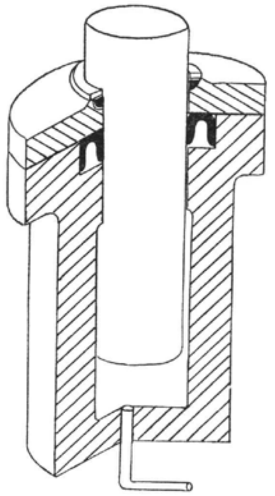

Fig. 4 *Hydraulic ram sealed with a U-packing at the top of the cylinder. The uppermost ring is simply to wipe dirt and grit from the descending ram. (After McNeil[8])*

cast', or with only perfunctory machining. The entire assembly is much quicker and cheaper to produce.

Bramah or Maudslay?

Samuel Smiles, in one of his influential volumes,[6] claims that the U-packing that made hydraulic machinery practicable was in fact invented by Bramah's talented foreman Henry Maudslay. Both were certainly astute enough to appreciate the advantages of transferring a cup washer at the base of the piston to an analogous annular device encircling its circumference at the top. Several biographers[7,8,9] have since challenged Smiles' statement – and an independent claim has also been put forward [9,10] for Benjamin Hick on the evidence of a press he built in 1813. It seems to me likely that, after joint discussion, Maudslay would most likely have *made* the first U-seal in the early 1800's, perhaps by using a vice to squeeze a ring of oil-soaked leather into a suitable mould and then trimming the lip in a lathe.

Whatever the details, the early hydraulic press was known universally as a Bramah press, both he and Maudslay would have benefitted from sales, and the two men appear to have remained friends until Bramah's death in 1814. The firm was continued at its Pimlico premises by Joseph's eldest son Timothy, who had joined his father in 1813. Within a few years the second son, Francis, joined his brother. The press appears to have been available to order in a range of sizes, from a small 'portable' model to massive presses for permanent industrial applications.

Control Valves

The hand pump on the Bramah press acts as both a lift pump to draw the working fluid from the reservoir, and as a force pump to send it to the hydraulic cylinder. One-way valves are therefore required in both directions. Bramah does not comment on these, but probably used metal cones seating in matching sockets. Much smaller in diameter than the ram, sealing problems would be less severe.

A manual screw-down by-pass is required to allow the fluid to return to the reservoir when the press has done its job, and the ram is required to descend.

The 'Faraday' Press

An early purchaser of the smallest press was the Royal Institution, paying 25 guineas[11] for it in 1818 (Fig. 5). This was at the instigation of Michael Faraday, who used it to squeeze crystals of his newly-discovered benzene (m.pt. 5.5° C) between sheets of bibulous paper.[12,13] This was to separate them from oily contaminants with which they were mixed in fractions distilled from 'gas-oil'. The latter is obtained from natural petroleum, but I am unable to see why a hydraulic press was required. Surely it would tend to close the pores of the paper and express any contained liquid!

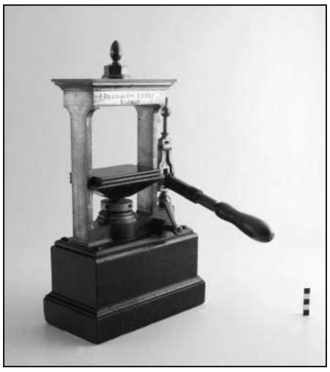

Fig. 5 *Faraday's hydraulic press at the Royal Institution. (Photograph courtesy of the Royal Institution.)*

The press is now displayed in the refurbished galleries of the Royal Institution. Its 2-inch diameter ram and a likely fluid pressure not exceeding 2000 psi suggest that a maximum upwards force of 3 tons between platen and frame would be a reasonable estimate. There is no external sign of a spring-loaded relief valve to guard against over-enthusiastic pumping, but the manual release valve allowing the ram to descend is visible below the pump handle.

Bramah (or Maudslay) must have relied upon experience when designing a 3 inch o.d. chamber to contain the ram, but its 0.5 inch wall agrees well enough with the 0.4 inch recommended for cast iron by Barlow's tables[14] of 1836, allowing a safety factor of three.

Bramah's Original Press

Frank James[15] has found some further intriguing entries in the Minutes of the Managers of the Royal Institution:

> 3 May 1819. Messrs Timothy and Francis Bramah presented through Mr Millington the original Hydraulic Press invented and made by their late father Mr Joseph Bramah, being the first Machine that was constructed on a large and powerful scale.
>
> 6 April 1846. At the suggestion of Mr Faraday Resolved that Bramah's Press be presented to the Museum of Economic Geology. (Bramah's old factory in Pimlico had been destroyed by fire three years previous to this date[8])

It would seem likely that the press referred to is the timber-framed machine shown in the patent drawings. The Geological Survey and the Museum of Natural History at South Kensington inherited the maps and collections of the Museum of Economic Geology, but have no records of any press accepted as a gift. It would appear of very little use to them! The Science Museum has(in its large objects store) only the mighty 'steelyard' hydrostatic balance made by Bramah in 1796 to demonstrate the power of hydraulics,[9] but it does possess an extensive archive of Bramah-related drawings and plans. The small press displayed at the Royal Institution appears to be the only extant example of a Bramah hydraulic press.

Chevron Packing

The modern descendant of the U-packing is the chevron ring. Shown diagrammatically in Fig. 6, it will be seen how the entry of pressurised fluid into the interior of each inverted vee-ring will cause it to expand radially inwards and outwards, the lips gripping both ram and housing with a force proportional to the hydrostatic pressure. It (and its variants) are widely used in hy-

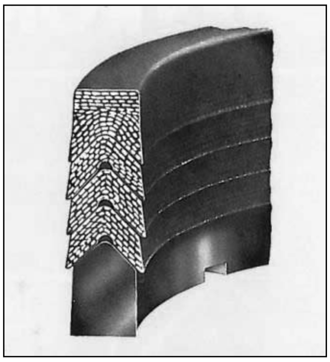

Fig. 6 *Chevron packing. (Courtesy of James Walker Ltd)*

draulic machines of all types (e.g. the JCB excavator) at pressures ranging up to some 2000 psi (say 1 ton per square inch).

Still Higher Pressures

To withstand still higher pressures more chevron rings may be added to the stack. For example, oceanographic instruments intended to work at the bottom of the Marianas Trench must withstand 15,000 psi. However, it is possible to achieve 100,000 psi in small volumes within massively reinforced cascaded chambers. Ironically, still higher pressures can be exerted *by hand* upon thin films within 'diamond anvil' cells![16]

Notes and References

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3. Simon Stevin, *De Beghinselen des Waterwichts,* 1st edition (in Flemish) (Leyden, 1586). Latin edition 1608.

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Book Review

Opinions expressed by reviewers are their own, and not necessarily reflect the views of the Editor or the Society

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Many members will know the Scientific Instrument Commission (SIC), which encourages research into the history of instruments and their use as evidence in the history of science more generally. Some will even have attended the successful symposia it organizes. While papers from meetings have appeared in various publications in the past, this is the first in a new series of thematically focused volumes that will draw some of the research together more formally. As an organization with so much in common with the SIS, including a shared President, any book published under the SIC banner will be of interest to readers of the *Bulletin*.

This collection brings together papers given in Dresden in 2004, and focuses on the collecting of scientific instruments in Europe between 1550 and 1750, with two papers looking at the later collecting of instruments made in this earlier period. As a result, the volume is very much about the high end – beautifully crafted instruments by makers like Schissler (Fig. 1) and Arsenius, which today's collector can only dream of owning. It is good to see, therefore, a good number of colour and black and white illustrations of these treasures.

Given the conference's location, it is no surprise that several papers concern the Dresden collections and the activities of Augustus, Elector of Saxony, who in the second half of the 16th century assembled what must have been an extraordinary collection, judging by the records and those instruments that survived the Second World War. The remaining pieces draw on other significant collections, including those at Hesse-Kassel, St Petersburg, Krakow, Florence and the Escorial.

Part of the book's strength lies in the thematic links between different chapters. These concern not only the growth of collecting as a defined activity, but also interesting perspectives on the different roles that instruments and collections have played over time. For the period in question, the finest instruments underpinned the assertion and display of political and sovereign power. This is something the Dresden collections illustrate well, since it becomes clear how powerfully their symbolic role was deployed, with their notionally practical uses reflecting local political and economic contexts – hence the prominence of mining and surveying technologies in the Elector's collections.

This wasn't just a Dresden thing. Filippo Camerota, for instance, describes the political role of science and its instruments at the Medici court, while Tatiana Moisseeva shows how instruments became vehicles for the introduction of new scientific knowledge through Peter the Great's collections in St Petersburg in the early 18th century. Many other interesting tales also emerge. Sven Dupré and Michael Korey show in their extensively footnoted piece, for example, that the movement of objects into and out of collections was significant: eyeglasses added to the Dresden *kunstkammer* in the sixteenth century were removed in the 1620s, considered less wondrous than the newly invented telescopes more recently acquired.

Much here sets the reader thinking about the changing roles scientific instruments can have according to their contexts of manufacture, ownership and use. Indeed, one of the few criticisms is that some pieces left me wanting more. In part, this is because the chapters derive from short papers delivered at SIC meetings, although some, such as Koenraad Van Cleempoel's discussion of the library of the Escorial, have taken the opportunity to develop their discussion. Overall, however, this is a welcome and auspicious beginning to a series that will hopefully continue to present the latest research into the history of instruments, offering rich insights as new findings emerge. For those who can afford the cover price, it is well worth dipping into.

Richard Dunn