THE DEVELOPMENT OF A HYDRAULIC PULSE GENERATOR FOR BREAKING ROCK IN THE MINING INDUSTRY

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The aim of this research was to develop a non-explosive mining or quarrying device which fractures rock through the application of liquid pressure pulses into drilled holes, a process requiring a peak pressure of approximately 250 MPa, with a rise time of about 0.5 ms. A full-scale machine was designed, built and tested, using air for energy storage and a moving piston as the energy transfer medium. It utilises a double diaphragm mechanism to abruptly pressurise the back of an 80 kg piston of diameter 200 mm, which thereafter impacts with a further thin diaphragm enclosing water in a cavity (to simulate the hole in rock) comprising a thick-walled steel cylinder of internal dimensions 40 mm diameter × 1000 mm deep. An LVDT was used to monitor the piston displacement whilst a pressure transducer tracked the hole pressurisation. Measurements conducted over a range of gas precharge pressures corroborated satisfactorily with computational predictions. The device released approximately 18 kJ into the liquid section, with associated peak pressures in excess of 300 MPa and rise times of about 0.7 ms, using the maximum gas precharge pressure of 9.2 MPA. Overall energy transfer efficiencies varied in the range 70% to 80%. In conclusion, the research validated the basic concept that large pressures for fracturing rock could be rapidly and efficiently generated through the impact of a moving mass on a column of water filling a hole.

Introduction and objectives

It is well-established that the concept of continuous mining has the potential of substantially improving the viability of mines. According to Haase and Pickering,[1] 'the fundamental obstacle to major improvements [in mine profitability] is the use of explosives to break rock. Blasting is the major cause of lack of mechanisation, poor labour productivity, and poor utilisation of capital and equipment.' Arising from this perspective, the broad aim of the current research was to develop a non-explosive (continuous) mining device in order to circumvent the inefficient blasting cycle and thus improve mine profitability. Although alternative systems were considered, from an early stage in the project the specific mechanism under consideration was one which fractures rock through the application of liquid pressure pulses into predrilled holes. A critical survey of the literature[2,3] indicated that the multiple fracture of rock requires a peak pressure of approximately 250 MPa, with a rise time in the approximate range 0.5 to 1 ms.

Hence the specific objectives of the research were as follows: (i) the design of a full-scale laboratory prototype to produce requisite levels of energy, maximum pressure and pressurisation rate; (ii) manufacture and testing of the device; (iii) the development of a computer simulation; and (iv) the reconciliation of test results and predictions, in order to validate computer modeling as a suitable tool for optimising the design of such devices.

Physical and computational modeling

Most devices of the type under consideration may be broadly characterised according to the manner in which the following physical mechanisms and characteristics are incorporated:

1. An energy storage medium (gas or liquid).
2. An energy transmission mechanism.
3. An energy transmission medium.
4. An energy release mechanism
5. The medium in the hole.

Clearly, various options and possible combinations exist of the above factors. For example, a device such as the Hydrex developed by COMRO (now Mining Technology, CSIR), employs water (at approximately 400 MPa)

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as its storage medium, with the same medium both in the hole and for energy transmission. Energy release is achieved by a rapidly opening valve which allows transmission to the hole via expansion of water in the machine, commensurate with high pressure compression of water in the hole leading to fracture, and lower pressure flow of water into the hole subsequent to fracture. A detailed analysis was undertaken of the merits associated with air versus water as energy storage media, from which it was concluded that the former was more viable, for the main reason that it possesses a much larger energy storage capacity, i.e. for a given pressure air stores many times more energy than water. There is a proviso that the maximum air pressure be constrained to values which comply with safety regulations (not to exceed approximately 20 to 25 MPa). Analytical and computer modeling were used to evaluate several ideas. On this basis the most effective was found to be a 'kinetic energy' concept which employs air for energy storage and a moving piston as the energy transfer medium. For this specific system the pressure rise in the liquid cavity and variations of piston velocity are governed by

$$\frac{dp_{H_2O}}{dt} = \frac{\beta_{H_2O}}{V_{H_2O}} U A_{H_2O}; \qquad (1)$$

$$\frac{dU}{dt} = \frac{p_{gas}A_{gas} - p_{H_2O}A_{H_2O}}{M}; \qquad (2)$$

$$p_{gas}V_{gas}^{\gamma} = p_{gas}V_{gas0}^{\gamma}. \qquad (3)$$

where A_{gas} and A_{H_2O} are the areas in contact with the gas at pressure p_{gas}, and the water in the hole at pressure p_{H_2O} respectively; β_{H_2O} is the bulk modulus of the water; V_{H_2O} is the water volume; M is the piston mass; $U(= dx/dt)$ is the instantaneous piston velocity; $\gamma = 1.4$ is the adiabatic constant for air, given by the ratio of specific heats c_p/c_v; and $V_{gas} = V_{gas0} + A_{gas}X$.

A system based on this principle was computationally optimised and a full-scale machine was designed and constructed (Figure 1). It utilises a double diaphragm mechanism to abruptly pressurise the back of an 80 kg piston of diameter 200 mm. Once the piston has accelerated (in air) to its maximum velocity it impacts, with a further thin diaphragm enclosing water in a simulated 'hole' which comprises a thick-walled steel cylinder of internal dimensions 40 mm diameter × 1 000 mm deep. An LVDT was used to monitor the piston displacement, while a pressure transducer tracked the hole pressure variations with time.

Tests were conducted[4]over a range of gas precharge pressures, between 1.3 and 9.2 MPa. Measurements were made of liquid pressure and piston displacement with time, from which piston velocity variations and energy transfer efficiencies could be obtained, after data processing.

Results and discussion

Comparisons with predictions

Figures 2 and 3 show, respectively, predicted and measured variations of liquid pressure with time and diaphragm bursting pressure (as three-dimensionsal surface plots) for all the tests that were conducted. Within experimental variability, acceptable corroboration was obtained between the two sets of data. Figures 4 and 5 represent the same data plotted in a two-dimensional reference frame. Figures 6 and 7 show, on the same sets of axes, typical measurements and predictions of piston position variation with time, whilst Figures 8 and 9 give the corresponding velocity variations.

Comparisons between measured and theoretical maximum liquid pressures generally showed a variance of only 5%, whilst discrepancies in piston displacement and velocity were between 5% and 15%, ascribed to air pressure build-up ahead of the moving piston, leakage of water from the nozzle section, air contained in the nozzle, and deflection of the connecting rod between the piston and displacement transducer.

Functionality of the device and application to the mining industry

The current device comfortably achieves in excess of 300 MPa in about 0.7 ms (corresponding to about 18 kJ of energy released into the hole), using low pressure air as the driving mechanism.[1] Overall energy transfer efficiencies (from expansion of the compressed gas to compression of the liquid in the test section) varied in the range 70% to 80%. The machine has the attraction that it is not kept at elevated pressures for prolonged periods of time. If required it would be quite feasible to achieve upwards of 500 MPa, using an upgraded form of the same concept. Furthermore, the machine is simple in construction, has only one moving part (the piston), and does not rely on precision sealing of the high pressure sections. It has a mass of about 250 kg and can easily be fitted into a 1 m stope, provided it is suitably supported.

Despite great promise shown by the concept there are several issues which require attention, none of which appears to be insurmountable:

1. The diaphragms required to activate the device were intended only as a laboratory measure and would

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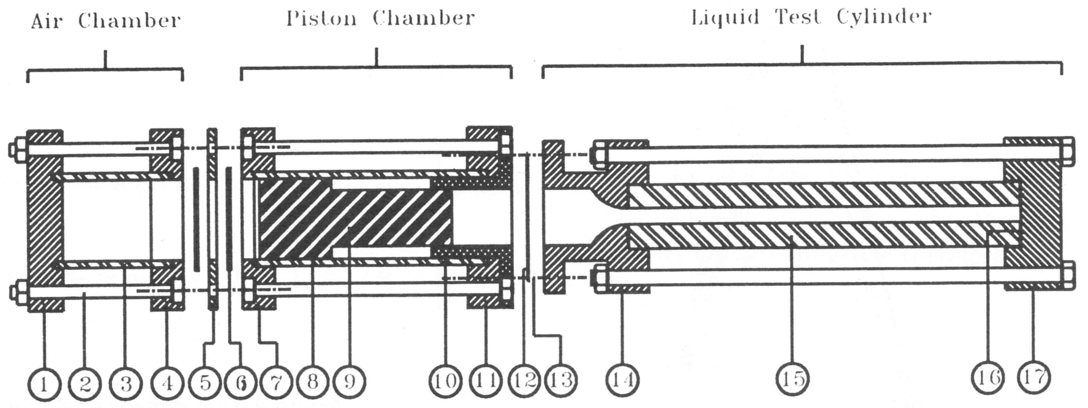
[1] Although the device was tested to an initial (maximum) air pressure of 9.2 MPa, only 6.5 MPa was needed to achieve the requisite 250 MPa.



1	Endcap	7	Flange	13	Bolted Connection
2	Bolt	8	Tube	14	Nozzle
3	Tube	9	Piston	15	Cylinder
4	Flange	10	Collar	16	Sealing
5	Disc Separator	11	Endcap	17	HP Endcap
6	Rupture Disc	12	Diaphragm		

Figure 1 Assembly drawing of hydraulic rock breaker

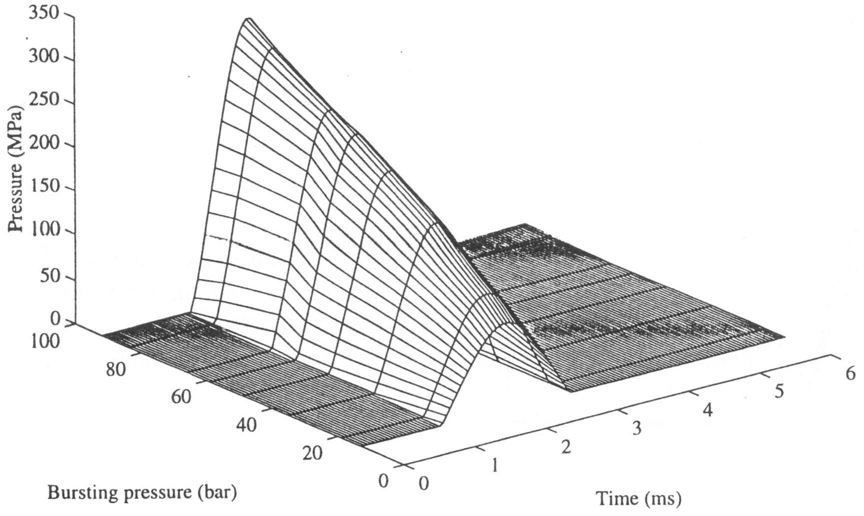


Figure 2 Surface plot of predicted pressure variations with time and bursting pressure

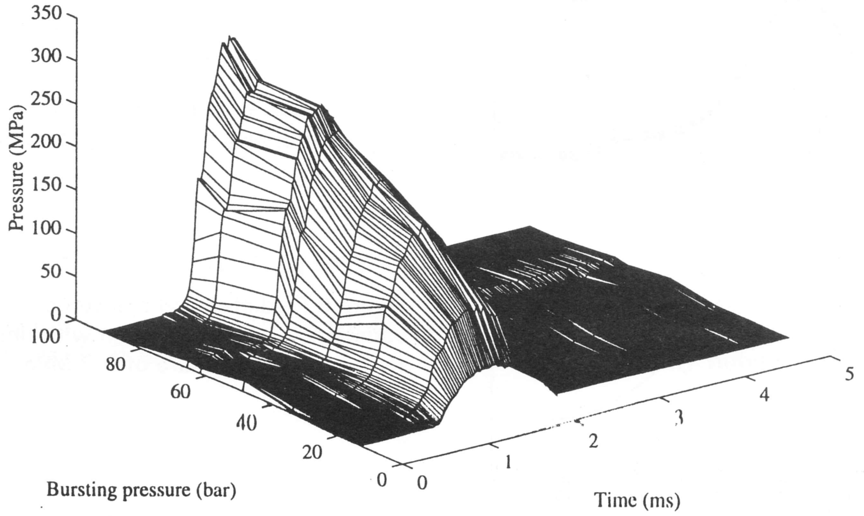


Figure 3 Surface plot of measured pressure variations with time and bursting pressure

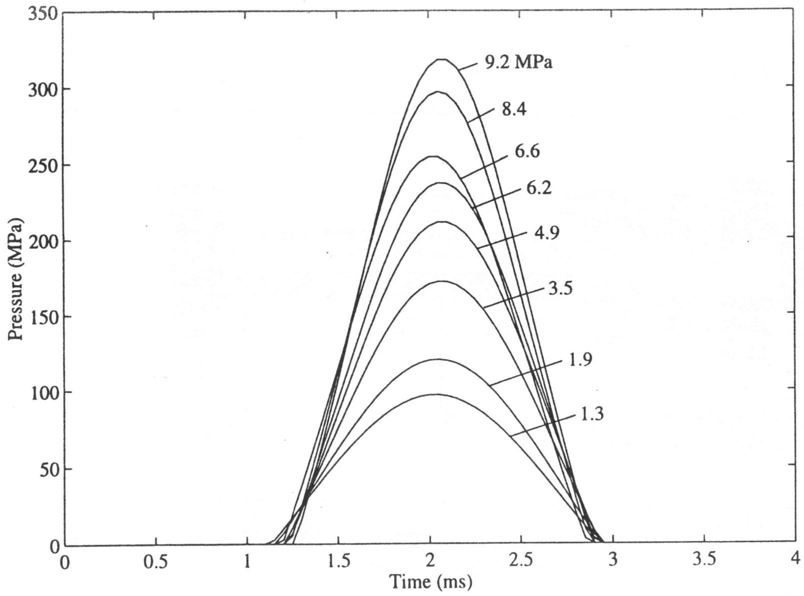


Figure 4 Two-dimensional plot of predicted pressure variations with time and bursting pressure

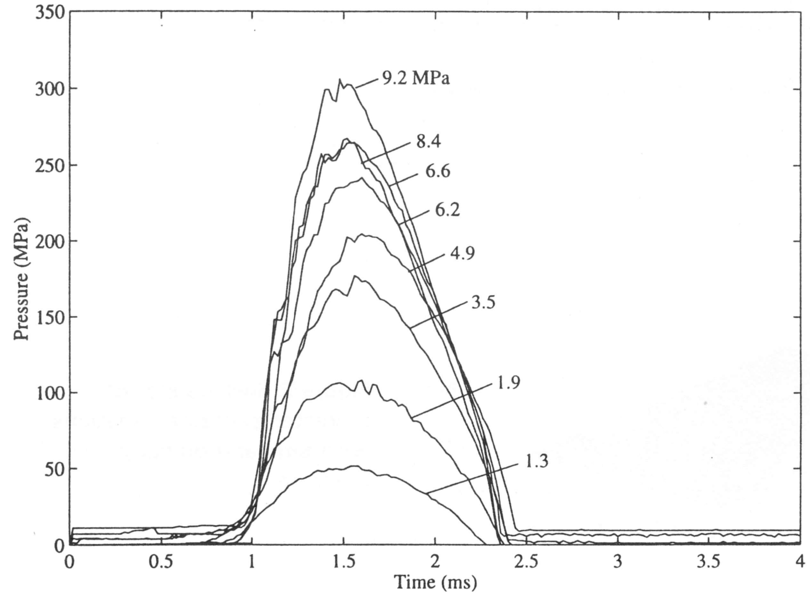


Figure 5 Two-dimensional plot of measured pressure variations with time and bursting pressure

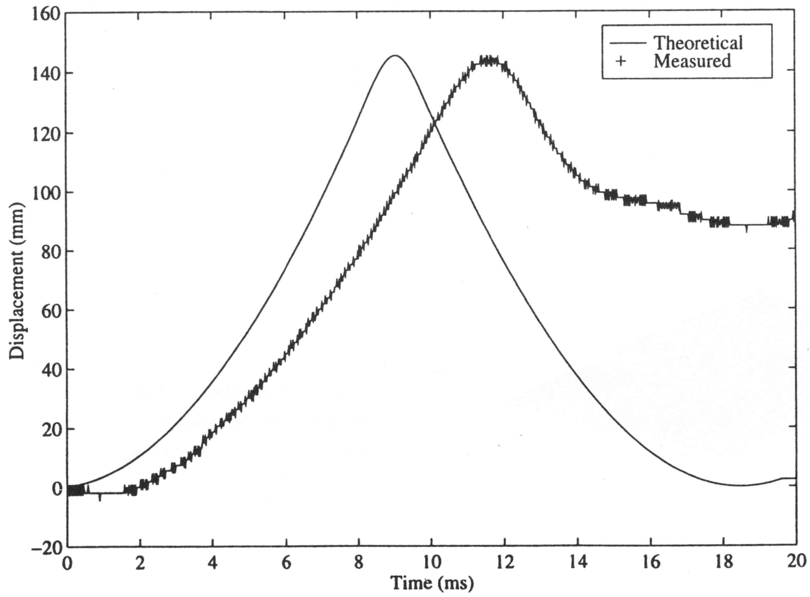


Figure 6 Predicted and measured variations of piston position with time for a bursting pressure of 9.2 MPa

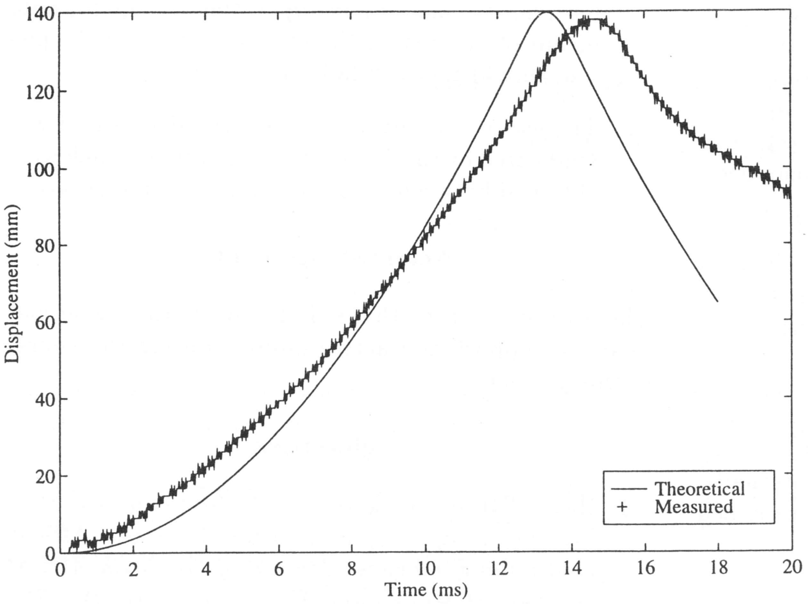


Figure 7 Predicted and measured variations of piston position with time for a bursting pressure of 1.9 Mpa

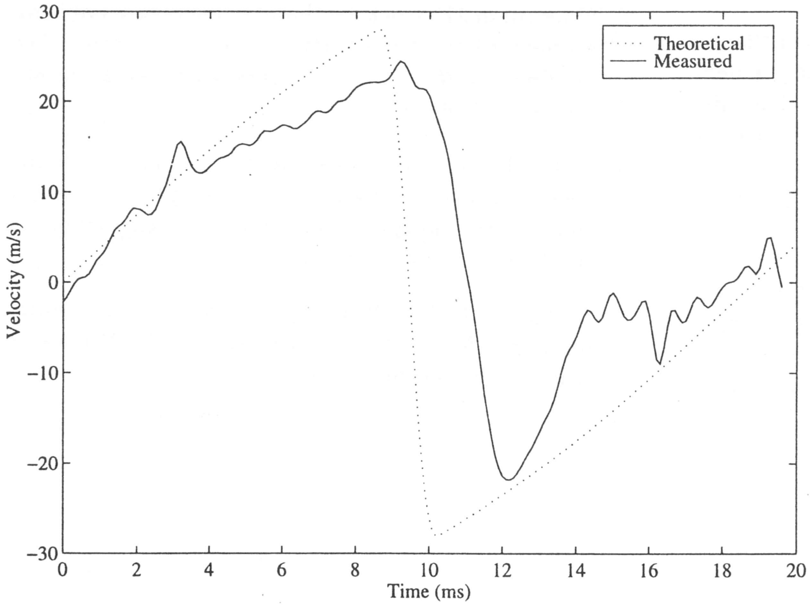


Figure 8 Predicted and measured variations of piston velocity with time for a bursting pressure of 9.2 Mpa

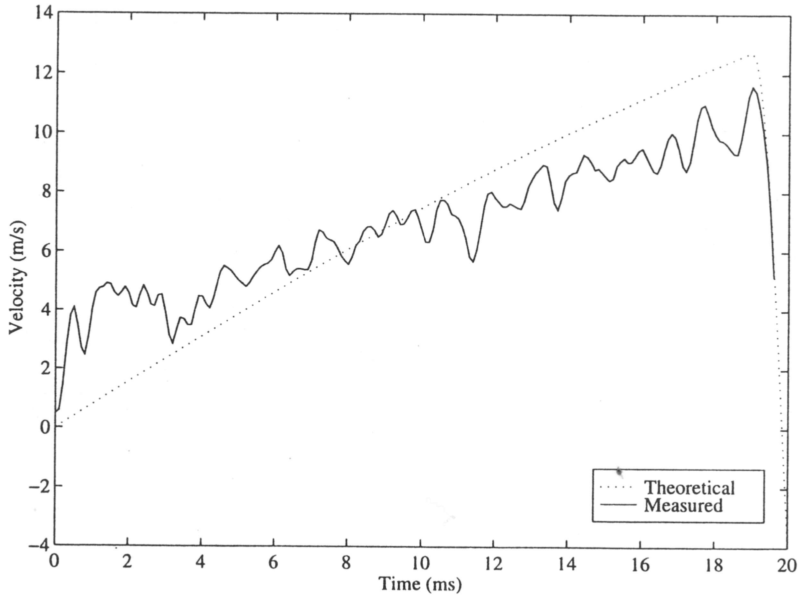


Figure 9 Predicted and measured variations of piston velocity with time for a bursting pressure of 1.9 MPa

obviously not be feasible in the context of a production unit. However it was encouraging that the machine achieved its performance with 'petalling' of only the central portion of the diaphragms (approximately one third of the potential flow area), suggesting that any subsequent valve mechanism need not be too large to achieve the desired results.

2. In the laboratory context no turnkey mechanism was provided to re-load the machine: the piston and diaphragms were manually re-positioned prior to recharging and firing.
3. No 'buffering' capability was provided: in the event of the rock offering no resistance, the kinetic energy of the piston would have to be dissipated internally, with an appropriate hydraulic mechanism provided for that purpose.

Conclusions

1. The research validated the basic concept that large hole pressures could be rapidly and efficiently generated through the impact of a moving mass. The laboratory device comfortably exceeds the published performance requirements for the multiple fracture of rock and therefore shows promise as a practical mining concept.
2. Successful implementation of the concept will depend on (a) designing a practical valving system to replace the diaphragms used on the laboratory facility, (b) providing a turnkey recharging and firing mechanism, and (c) incorporating an appropriate means of dissipating the energy by slowing the piston, should the rock fail prematurely.
3. The use of computer modeling as a design tool was vindicated by the favourable correlations which were obtained between measurements and predictions.

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