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Fast Data Capture for Crusher Modelling and Optimisation

J.D. SALTER, I. JOSEPH and L. NORDIN

Mines Division, De Beers Diamond Research Laboratory, Johannesburg

Most diamonds are liberated from their ores by crushing. Diamond and other coarse grained mineral ores require carefully optimised crushing circuits. Recent advances in computer technology have made possible the on-line capture of crushing plant performance data and, hence, the accurate empirical modelling of the crushing process. Such models are used in simulation studies to determine the optimum operating conditions for a given plant.

A system is described which allows operating data from mineral treatment processes to be logged. Up to 16 channels of data may be recorded simultaneously at sampling rates in the kiloHertz range per channel. A data storage and analysis procedure is described which allows the system to make full use of its sampling capabilities.

Introduction

Crushers normally perform comminution duties for ease of materials handling or for milling circuit feed preparation. They are consequently often overlooked when liberation circuits are optimised. However, some branches of the minerals industry make use of crushers in different roles - for example, for coarse mineral grain liberation. This requires carefully controlled, optimised crushing circuits.

Crushing circuits are generally optimised within the framework of either an operating and/or economic philosophy or a liberation philososphy. An example of the former is that employed at Bougainville Copper Limited where the operating philosophy is to apply, and use, maximum crusher power draw to maintain a continuous supply of crushed ore to their mills at the finest possible size.[1,2] The classic example of optimisation according to a liberation philosophy is provided by the diamond industry.

Most diamonds are liberated from their ores by crushing. The crushing circuits are operated such that they liberate all economic diamonds at their natural grain size, i.e. unbroken. This is achieved by employing stage crushing and concentration techniques where each stage is carefully optimised within the constraints of a plant's overall liberation philosophy. In essence this means that after a crushing stage where the ore has been reduced to 100% passing x mm, all diamonds larger than y mm (where x > y) have been liberated and recovered. Therefore, the next crushing stage must employ a minimum crusher gap of y mm to avoid diamond breakage.

Detailed liberation philosophies vary from mine to mine since headfeed diamond size, grade, and value distributions vary greatly. However, they all have one feature in common - they aim for perfect diamond liberation. No other branch of the industry suffers such economic penalties for imperfect liberation.

Model development

General

Satisfactory plant performance is relatively easy to achieve; optimum performance can only be achieved by relatively sophisticated analysis and control. The first phase of any optimisation campaign is the development of a mathematical model of the process so that it may be simulated. Although simulation studies based on Whiten's perfect mixing model (3,4) have proved successful in outlining broad crushing plant optimising strategies, they have not, to date, been able to perform detailed circuit optimisation. Therefore, steady-state empirical models, which relate crushing performance to the operating variables, have to be developed for each circuit. This requires the acquisition of data, by planned experimentation, from the process over a wide range of normal or expected operating conditions, and appropriate statistical analyses of these data. Examples of empirical crusher models and their use have been published. (5,6)

Requirements

The requirements for good crusher circuit modelling are:

1. The circuit should be controllable so that steady state conditions may be easily achieved and maintained during the course of the testwork.
2. The process variables should be clearly defined and their ranges of values established.
3. Good experimental design and techniques.
4. Good process instrumentation.
5. Good data capture and analysis facilities.

Since the crushers (with the exception of primary units) are invariably operated under 'choke fed' conditions, simple crusher feed level control has been implemented on most plants. (Power control has been found to be less sensitive to process changes.) Where manual control is still in operation, level control is implemented for the testwork and verification phases, and is retained thereafter.

The process variables and their ranges of expected values are largely known from prior experience. For example, in common with published findings, (6) it is usual to accept as constant the crusher variables - head angle, throw, and speed since they have minimal influence on product fineness. However, surprising effects have been observed, for example, with changes in crusher feed surface moisture content.

Experimental design and techniques are relatively simple in most cases, though careful planning is required to allow the plant under study to meet its production call.

Process instrumentation is fairly standard throughout the industry, e.g. weightometers, power transducers, infra-red moisture meters, etc., and calibrated 4-20 mA instrument signals may be collected from all modern units. Reliable on-line coarse particle size analysis instruments still need to be developed so that tedious feed and product(s) sampling and screening may be dispensed with. Another weak point is the (usually inaccurate) measurement of the closed side setting of Symons crushers by leading - a task which is slowly being replaced by instrumental methods (7).

Data capture

General

Good instrumentation has been available for some years to measure most of the necessary process variables. Only in recent years, however, has data capture equipment matched this performance - relatively inexpensive, rugged, plant-reliable equipment is now available which is fast enough to record rapid changes in process conditions. For example, the data capture equipment used in studying diamond liberation circuits has progressed as shown in Table 1; the choice of equipment being dictated by the needs of the time.

Initial work with chart recorders showed that laborious trace digitising and data transfer to a computer was unacceptable and that chart recorders are unsuitable except where only long-term trends are being sought. The Apple IIe and Macintosh computer systems provided partial solutions to these problems. They did, however, suffer from poor dust tolerance levels and data capture speeds (Macintosh)

TABLE 1. Changes in data logging equipment used by the DRL

Year	System	Number of channels	Sampling rate per channel
1980	multipen chart recorder	4	analog continuous
1982	Apple IIe computer with A/D interface; interpreted BASIC program; data written to RAM, transferred to diskette.	4	digital up to 1 kHz
1984	Apple Macintosh computer with Optomux computer A/D interface; interpreted BASIC program; data written to hard drive or diskette.	8	digital 1 Hz
1985	Olivetti M24 with PC-26 A/D card, Tallgrass 6150 hard drive/tape unit; compiled Turbo-Pascal programs; data written to RAM disk, transferred to hard drive and tape.	16	digital up to 35 kHz

or limited sampling time spans (IIe). In addition, data transfer to the IBM mainframe computer used for the analyses proved very difficult. All these problems were overcome by the present Olivetti M24 (IBM-PC compatible) system.

The present system

Research into crushing phenomena indicated that sampling speeds of approximately 50 Hz are required to 'see' the true variations in crushing variables. A system was required that would be able to record data at this rate from at least eight channels, and often from up to sixteen channels, over extended testwork periods. In addition, the system had to be able to capture data over long (± 3 months) model verification periods - a task for which the previous systems had proved adequate. The final criteria were that the large bodies of data collected should be easily and securely transported from remote mine sites to the Diamond Research Laboratory (DRL) for analysis; be easily ported to an IBM mainframe computer; and that the system should include an option for analysing the data on-site if necessary. These conditions were met by the following system

Hardware

The system is based around an Olivetti M24 computer fitted with a maths co-processor. This computer was chosen because of its relative cheapness, fast processing speeds, and direct compatibility with IBM equipment.

Analog to digital (A/D) conversion facilities are provided by a PC-26 card (manufactured by Eagle Electric Ltd of Cape Town, South Africa), which is plugged into the Olivetti. This low cost card is adequate for most in-plant needs but for more complex tasks it may be replaced by the more versatile Dash16 card (manufactured by Metrabyte of Massachusetts, U.S.A). It should be noted that A/D cards offering sampling speeds of up to 1 MHz are now available. Their use in the minerals industry is, however, restricted to fundamental laboratory studies such as those involving particle breakage, for which ultra-fast instrumentation is now being developed. (8)

The 4-20 mA input signals to the PC-26 card are isolated using standard signal isolators and then converted to the correct input voltage range using precision resistors.

Captured data are stored initially on an internal RAM disk before being copied to the 50 Mbyte hard drive of a Tallgrass 6150 unit (maufactured by the Tallgrass Corporation of Kansas, U.S.A). Upon completion of a particular testwork phase, the entire contents of the hard drive are backed up onto the Tallgrass's 60 Mbyte tape cartridge system. The Tallgrass unit was chosen because it is reliable, has sufficient hard drive/tape storage for most applications and , aside from meeting the criteria set for the system, the tape facility enables :

1. long or short term archiving of data (recommended shelf life ± 10 years);
2. transfer of large data files for analysis with minimal disturbance of the data logging process; and,
3. backup of important data for safety reasons.

Initially, data were written directly to the hard drive. However, it was found that the time between samples varied as a function of the distance that the read/write head of the hard drive had to travel. In order to ensure consistent sampling times, the data were therefore written to a RAM disk (a pseudo disk drive in the computer's memory) and transferred to the hard drive after the completion of a sampling phase.

The hardware is completed by a colour monitor, a dot matrix printer, and an uninterruptible power supply. The Olivetti/Tallgrass combination is housed in a custom-made, positive-pressure, rugged flight case and the printer in a separate dust-proof enclosure. Currently there are three such systems in use for crusher studies, two for fundamental particle breakage studies, and two for other process investigations.

Software

The system software was custom-written in Turbo-Pascal, an extension of UCSD-Pascal. No working knowledge of Pascal, the Olivetti, or MS-DOS is required in order to make use of the suite of programs: all the programs are menu-driven.

Two data logging programs are currently in use, 'Fastlog' and 'Slowlog'.

Fastlog is used specifically for data collection for modelling purposes and Slowlog for model verification/trend analyses.

Fastlog allows the user to specify the following from the control menus:

1. sampling period (minutes), number of channels to be sampled (max. 16), sampling rate (max. 35kHz), sample identifier (e.g. mine, material, test number);
2. select channels to be shown on screen;
3. display data graphically or numerically; and,
4. display data as engineering units, raw counts, or milliamps.

Having selected the appropriate conditions, the menus are exited and the screen then shows the desired data at the chosen sampling rate for the channels. Pressing the space bar initiates the data capture period. Upon completion of this period, the captured data are displayed and the user has the option to either save or discard them. Following the appropriate action, the system returns to displaying the current input data, and pressing the space bar will commence data capture again.

Fastlog accumulates data very quickly. In its first application, 8 channels were sampled at 50 Hz each, over 5 minute tests, generating 0.5 Mbytes of data per test. The hard drive was able to accumulate 90 sets of data before transfer to tape became necessary.

Slowlog is the default program automatically loaded when the system is powered up. This eliminates the need for a manual start-up in the event of an extended power failure. Set-up options give the user a choice of either a graphics display of any four of the channels, a numerical display of all channels, or statistical analyses of the logged data.

The program samples each channel ten times a second, averages these values over one minute and saves the means to disk. Sampling eight channels in this manner gives more than two years of data capacity on the hard drive. (The equivalent floppy diskette system would require a new diskette every 6 days.)

Custom software was developed in preference to the use of standard, commercial data capture and analysis packages such as ASYST for the following reasons. Most commercial packages have limited data collection capabilities, some are difficult to operate, and none offer the flexibility demanded by the present application.

Having decided to develop custom software the only remaining question was whether to use MS-DOS or a multi-tasking operating system such as XENIX. It was decided not to use a multi-tasking system since this would introduce unequal time intervals between data samples. In addition, the availablity of standard data analysis tools, such as LOTUS 1-2-3, operating under MS-DOS mitigated against using a multi-tasking system

Data analysis

A variety of analysis techniques is employed. The Slowlog data are analysed using a flexible, custom analysis program designed to pick out only the required features. More sophisticated procedures are necessarily used for the Fastlog data.

In general, all the Fastlog data from a particular set of tests are ported to the DRL's IBM mainframe computer (via an IRMA card link), where they are analysed using comprehensive Statistical Analysis Systems (SAS) software. [9] Experience has shown that most crushing circuits can be described by multiple linear regression models. Rare variations from linearity are countered using simple linear transformations.

Where it is not vital to employ the full body of data in model development, an analysis program calculates the moments of the particular data sets. These moments are then used to develop multiple linear regression models. This analysis program is also used at remote sites when circumstances do not permit the immediate return of the data to the DRL for analysis. In these cases, models are developed using commercial packages with multiple linear regression facilities.

The models developed for a particular circuit are then used to simulate that circuit to enable the optimum operating parameters to be established. These simulations are conducted using simple equation solvers. [10,11,12]

Applications of the system

The data capture and analysis system has been used in two main applications. The first is the optimisation of existing crushing circuits and the second is the evaluation/optimisation of new equipment. In the former application, the details of which remain confidential, significant process improvements have been made following the implementation of the optimised operating conditions. The benefits of using the system to evaluate new equipment have been just as significant: stringent evaluation and/or optimisation testwork has been easily and rapidly conducted, saving production and research resources. More recently, the system has been used in studies of both dense medium and sorting plants.

Conclusion

Data capture and analysis techniques have progressed to the point where process analysis and optimisation procedures are relatively quick and inexpensive. Their application is becoming more widespread, and their economic benefits substantial.

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