Best Practice in Mechanical Sampling

Paul Reagan, of Sampling Associates International, US, reviews the best practice for the organisation and planning of sampling operations.

As ships are loaded at coal terminals around the world, the vast majority of cargoes are mechanically sampled. An improperly operated or poorly maintained machine will produce samples that do not truly represent the cargo and will result in improper assessments of penalties or premiums. This article will survey best practice for system operation and maintenance and highlight an important tool for sampling system operators – the calculation and charting of the sampling ratio.

The sampling system also prepares the sample

A mechanical sampling system does not just sample the coal but it also processes it. Each system consists of stages, each of which has a specific function. The first stage is the primary sampler. This is where the machine first touches coal. The primary sample is usually collected at a transfer point between two conveyors (where a falling stream sampler operates) or directly from the conveyor belt (where a cross belt sampler operates).

The material collected in each operation of the primary sampler is called an increment. Each increment, depending on the system design and the loading rate, can have a mass that ranges from 20kg to as much as 800kg. Many separate increments are collected for each sample (over 100 increments for a 10,000t lot of raw coal). Even the systems that produce the smallest mass increments quickly obtain more coal than can reasonably be transported to the laboratory. As a result, sampling systems are designed to process the coal so only a small, but unbiased, portion is retained and sent to the laboratory for analysis.

The processing includes both crushing (reduction in particle size) and dividing (reduction in mass). It is not uncommon for less than 1 per cent of each primary increment to be retained for analysis in the laboratory.

There are four essential elements of a 'best practice' sampling programme.

Good organisation and planning of sampling operations.

Measurements of operational performance.

Consistent maintenance.

An effective quality system.

Organisation and planning of sampling operations

The industry standards (ISO, ASTM, BSI, DIN, etc) that govern the practice of collecting samples contain the different specifications and rules to which mechanical sampling systems must comply. These rules determine such things as the minimum size of the apertures in the various sampling devices, the speed at which they should operate, the minimum mass of each increment and the size to which the sample is crushed.

With the design of the sampling system in mind, a sampling plan that adheres to the standards should be developed. These rules must be adhered to in both the collection of the primary increment and the subsequent processing. Because of these strict standards, an important first step in a successful operations programme is having good inspection practices.

Inspections

Inspections can be divided into two groups: those that take place while the sampling system is idle, known as static inspections, and those that take place while the sampling system is operating, known as dynamic inspections. It is good practice to have documented checklists that accompany both types of inspections. A standardised written checklist not only reminds the operator of all items that must be inspected but also serves as an historical record.

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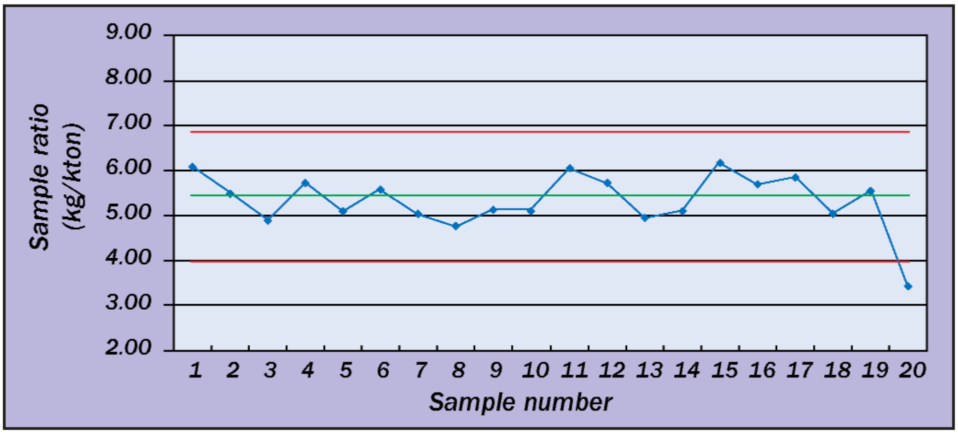

Figure 1. Control chart of sampling ratios.

Static checklists

Static checklists usually involve those items that must be verified prior to the start of sampling as well as items that are impossible or dangerous to check while the machine is operating. Examples of items that would be found on a static (non operating) check list would be cutter openings, the condition of the crusher interior and the belt wiping mechanism on the end of a cross belt sampler. One critical inspection item is how thoroughly the sampling system has been cleaned since the sampling of the previous consignment. Cleaning will be explained in further detail later.

Dynamic checklists

Some items on a system can only be checked while it is operating. These items would be found on a dynamic checklist. Examples would be the speed of cutters, the consistency of coal flow through the system, the proper timing of the frequency of cutters and the speed of feeder conveyors.

Some checklists are hybrids of both static and dynamic items. ASTM D-4702 and AS4264.5 are good places to start when looking for examples of checklists that can be useful to an operation.

Measurements of operating performance

In addition to the inspection of mechanical sampling systems, there are also some very important measurements of operating performance that need to be carried out. These measurements can be divided into two general categories – ongoing and periodic.

Ongoing measurement

All sampling systems are designed to operate according to certain design parameters. They are designed to collect a certain mass of primary increment (relative to flow rate), their internal belts transport the coal sample at certain rates, the crusher reduces the top size to a certain size, and the dividing stages reduce the sample by a chosen ratio. The result of the sampling system operating according to design is that for each set of parameters (lot size, size of cutter, speed of cutter, etc) the system is expected to produce a certain amount of sample mass per 1000t sampled.

The sampling ratio

The ratio of the mass of sample produced by the sampling system per 1000t sampled is called the sampling ratio. This is the most important indicator of sampling system performance. Its measurement, performed on a routine basis during operations, is an essential element of any successful mechanical sampling programme and the cornerstone of best practice.

As each sample is collected, sample weight and lot size data are recorded and observed sampling ratios calculated using the formula – sampling ratio = (sample weight x 1000) divided by the size of the lot (see examples in Table 1). Each of the sampling ratio values, the average sampling ratio value (CL-the central line) and the lower and upper control limits (LCL and UCL) are then plotted on a control chart (Figure 1). The lower (LCL) and upper (UCL) control limits are calculated using average moving range which is the absolute difference between the current sampling ration and the previous sampling ratio (see right hand column in Table 1). The LCL is equal to the CL minus 2.66 times the average moving range. The UCL is equal to the CL plus 2.66 times the average moving range. Any sampling ratio falling below the lower control limit or above the upper control limit is an 'out-of-control' point, and must be investigated. By investigation and resolution of the causes of out-of-control sampling ratios, one eventually achieves a sampling system that is operating in a stable condition.

Statistically, unless some special cause occurs, there is only a 1 in 100 chance of a ratio falling outside the control limits. As such, any samples with ratios outside the control limits are suspect and an inspection of the sampling system for special causes must take place immediately. Even if a special cause is not determined, vigilance is still necessary. If the operator makes the assumption that any ratio outside the control limits is a normal occurrence (and not due to a special cause), then he would be wrong in 99 out of 100 occurrences. If any special cause is found it needs to be corrected as soon as possible and the laboratory should be notified of a compromised sample.

In the control chart in Figure 1, the last sample is below the LCL. Some reasons for a low ratio are a coal blockage somewhere in the system, some debris in a cutter restricting its aperture, or the operator turning the sampling system off during extremely wet coal to prevent the crusher from plugging. Examples of causes of high ratios exceeding the UCL are a hydraulic leak that would cause a cutter to move through the stream slower than designed, a cutter that is not parked completely out of the coal stream, or an adjustable cutter opening that has loosened and opened up wider than designed.

Once the system reaches a stable condition, and after twenty or more sampling ratio values have been obtained, the average observed ratio is compared to the design sampling ratio (the ratio predicted by the design of the system). If the average observed ratio is not within 10 per cent of the design ratio, the difference between the two must be resolved.

Also, after the condition of a stable system has been reached, one calculates a measure of the variability of the sampling ratio, which is known as the CV or Coefficient of Variation. The CV is obtained by dividing one standard deviation by the average observed sampling ratio to obtain a number expressed in a percentage. CVs of less than 15 per cent indicate good sampling system performance. CVs of over 15 per cent demonstrate too much variation and action needs to be taken to correct some aspect of system performance. There will always be some variability in the sampling ratio and an outstanding CV would still be in the 5 per cent to 6 per cent range.

Periodic measurement

There are several important periodic measurements. Bias testing and measurement of the size consist of the crusher output are the most important.

The bias test is essentially a performance test of the sampling system to determine if there is evidence of system bias. The test entails a comparison of the samples collected by the sampling system to a series of manually collected reference samples to see if there are any biases introduced into the sample by the sampling system itself.

The agreed upon reference sample is almost exclusively a stopped belt sample where the main loading conveyor is stopped under full load and a complete cross section is manually collected (including sweeping all the fines off the belt with a small brush). A series of system samples and corresponding stopped belt samples are collected and analysed to measure overall system performance.

This test is always performed upon the commissioning of a new sampling system and then periodically throughout the life of the system. Before beginning the bias test for a new system, it is preferable to operate the sampling system, collect sampling ratio data, verify that the system is operating in a stable condition, confirm that the Coefficient of Variation is less than 15 per cent, and check that the average sample ratio is within 10 per cent of the design sampling ratio.

The question as to how often a sampling system should be bias tested is often argued. No one would dispute the importance of the test, but it is usually very costly and always disruptive to normal operations due to the many stopped belt samples that need to be collected (in some cases as many as 90 overall). As such, operations personnel would prefer it to be as infrequently as possible but quality control personnel want it as often as possible.

Adding to these considerations is the fact that some systems sample one million tpa while other systems sample 10 million tpa. Can one properly designate a time period for bias testing given such a disparity in volume?

As a general rule, well-maintained sampling systems, operating in accordance with design and in a stable manner, do not need to be bias tested any more than once every 3 to 5 years depending upon their volume. Systems should also be re-tested whenever there is a major component change. At terminals that load a wide variety of coals, selection of the coal to use for conducting the test is an important decision. It is prudent to select coal that is not so homogeneous as it might lead to a conclusion of no bias when there could be a bias when sampling coal with more variability, or blends of more than one coal.

Table 1. Example of observed sample ratio calculations.

Sample no.	Sample mass in kg	Tonnes in lot	Sampling ratio	Moving range
1	19.8	3250	6.09	
2	27.5	5000	5.50	0.59
3	23.4	4789	4.89	0.61
4	12.3	2145	5.73	0.84
5	12.0	2350	5.09	0.64

One other useful periodic measurement is to check on the size consist of the material produced by the sampling system after any crushing stage. Sampling system crushers are designed to produce a certain top size (4 mesh, 8 mesh, 10mm, etc.) for the final sample. However, crushers are usually high wear items and their ability to operate according to design can quickly degrade. This can impact the sample in the ability of dividers 'downstream' being able to operate properly (because they are also designed to work only on a certain top size coal).

Checking and tracking the performance of the crushers periodically, and at least monthly, will provide early warning of when the crusher components need to be replaced. Such checks are both a quality control measurement and a part of the maintenance programme.

Maintenance is essential

A good preventive maintenance (PM) programme is an integral part of proper mechanical sampling. In simple terms, a mechanical sampling system, even the most automated one, is a machine. As a machine, its components are subject to wear, breakdown, corrosion and malfunction. The result of such forces will be poor samples. Good maintenance of equipment is essential and it is necessary to ensure it is consistently performed.

In many cases the terminal or plant personnel perform the maintenance of the sampling equipment. While they are skilled and certainly have the ability to perform the maintenance, each day they are forced to select from their numerous maintenance priorities. When faced with a conveyor belt or a shiploader problem, the sampling systems slip to the bottom of the list. The condition of many sampling systems reflects the long-term effects of this daily slipping down the priority list. In many cases, unless it has completely stopped running, the sampling system does not get the attention it needs.

There are certain malfunctions that disrupt the system so much that the machine simply stops running and no sample can be collected for the laboratory. Such occurrences will always receive a response. However, there are problems that occur that can affect the sample but do not stop sample collection. In other words, coal sample continues to appear in the sample container but that sample is compromised. These latter cases must be detected and corrected.

Common problems

While there are too many examples of how poor maintenance can affect the quality of the samples to mention them all in this article, there are a few very common occurrences that illustrate the problem. In Figure 2, there is a diagram of a very simple piece of equipment, a conveyor belt scraper. The purpose of this scraper is to prevent coal fines from being carried back on the underside of the belt and to ensure that they remain in the processed sample.

In Figure 2 the scraper is worn and not doing its job. In the case of a typical steam coal, the fines contain higher ash and lower heat content. Instead of being scraped off the belt and remaining in the processed sample, with a chance to be included in the sample sent to the laboratory, these fines are lost. In this case, the sample sent to the lab will have a lower ash and higher Kcal than are really in the consignment.

Another common maintenance problem is on the sweep arm (cross belt) samplers. The primary samplers on this type of system are equipped with a hard rubber or plastic wiper, which actually makes contact with the conveyor belt to ensure collection of all the coal in the cross section selected. This is a high wear item. Access is often difficult and usually involves locking out both the sampling system and the conveyor belt to adjust it safely. Failure to frequently adjust and replace this wiper will cause the primary sampler to fail to obtain the coal (frequently the fines) closest to the conveyor belt.

A third and final example is poor maintenance of the parts of the sampling system that make it airtight – belt skirting, door seals and baffle curtains. One of the main sources of bias in a sampling system is change in the moisture content of the sample – introduced during sample collection and processing. Air will flow through many systems, particularly those with hammermill crushers, and care needs to be taken to prevent this tendency from drying out the samples. Failure to do so will allow a moisture bias to be introduced to the sample.

There are a number of main objectives of a PM programme.

To maintain the airtight integrity within the sampling system.

To ensure the sampling system does not introduce bias into the sample.

To be sure the system continues to operate as designed.

To prevent corrosion and to extend the useful life of the equipment.

To prevent rather than just react to problems.

This latter point is important. The sampling ratio described earlier is an invaluable tool in detecting problems. A well-planned and implemented maintenance programme, however, prevents many problems from ever occurring.

Records

A thorough PM programme requires a lot of documentation. Such documentation would include:

A log of all required PM checks and inspections which serves both as a reminder of the frequency of tasks and a record of when they are actually performed.

A written procedure for each PM task.

A written record of any failure during operations and the measures taken to correct it.

In a PM log, it is a good idea for sampling system PM to be scheduled based on the hours of operation rather than calendar time. An hour meter is simple to install for this purpose. That way, maintenance is performed according to the amount of use the system is receiving and the system gets checked more frequently during periods of high use.

Cleaning

It can be argued that cleaning is not part of maintenance and is more operations, but the fact remains that cleaning is important. Frequent cleaning of the sampling system prevents contamination between different coal consignments, prevents coal from drying out (or freezing) and being mixed with the next sample (even if it is the 'same' coal) and also is very important in preventing corrosion. Because coal can be wet, leaving coal in a sampling system encourages corrosion of components and housing steel. Good sampling practice necessitates frequent cleaning. Installation of compressed air stations at strategic locations around a sampling system is highly recommended to aid the cleaning process.

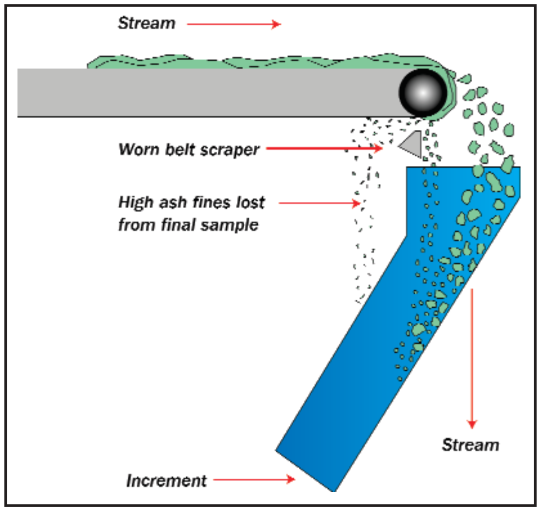

Figure 2. Belt scraper.

Quality system

A good quality system such as ISO 9002 is indispensable. While a full discourse on quality system requirements will not be offered here, it is important to cover one critical element: problem resolution. Great emphasis needs to be placed on problem resolution and correction. A sampling programme involves much more than the operation of a clean, well-maintained system. It also needs to deal with many variables such as the different sampling requirements of different consignments or clients, the ever-changing operational plans of the terminal or even such mundane things as a change in the load plan by the ship's master.

Problems will arise. Mistakes will be made. The critical element of any quality system is what is done about them. The first step is always to take the immediate action necessary for resumption of coal loading and sampling, and to determine the disposition of any suspect sample. Next, one must carefully examine the causes of the problem and determine the changes (in operating procedures, equipment, etc.) that are appropriate to prevent recurrence. It is this second, most important, step that is often neglected.

The ultimate resolution of any problem is preventing its recurrence. The goal of a quality system is continuous improvement. Continuous improvement requires that problems be documented, discussed, and examined (at all levels of the company) and that measures be implemented to keep it from happening again. Solutions to various problems range from changing an operational procedure to changing the type of equipment used at a certain stage of the sampling system. Whatever the resolution, continuous improvement requires commitment.

Conclusion

The four essential elements of the best practice in mechanical sampling have been identified. Of course, the proper implementation of these elements comes down to the people responsible for execution. Many well-designed programmes fail to achieve the intended results because the people responsible do not perform.

As such, responsible personnel need to be well trained. They need to understand what the machine is doing and, more importantly, how to identify when it is not working properly. If possible, it is good practice that the people that operate the machine also participate in the execution of the PM programme. This provides the double benefit of solving the low priority that traditional maintenance personnel give to sampling system maintenance, and it provides the operating personnel with valuable information on the inner workings of the components of the sampling system. Involvement in the execution of the PM programme will provide them with enhanced abilities to detect and prevent potential failures.

However, good training requires resources. The bottom line on a truly good sampling programme is that the people that write the cheques ensure that sampling is given the necessary emphasis. Since sampling is so important, its status needs to be made clear by senior management.

In the international coal trade, proper sampling is taken for granted. Ultimately it should be because good sampling means trade takes place without incident. As such, a good sampling programme, which runs without incident, becomes 'out of sight, out of mind'. But there is a difference between being taken for granted and being neglected. It can only be taken for granted when the proper care and attention are provided.