The **Metcom Grinding Process Management System**

MODULE #5:

FUNCTIONAL PERFOMANCE OF BALL MILLING

Metcom Technologies, Inc.

TABLE OF CONTENTS

	page
Objectives	1
Introduction	2
PART I - The Elements of the Functional Performance Equation	11
Circuit output of fines	11
Classification system efficiency	16
Effective mill power draw	24
Ball mill specific grinding rate	29
Ball mill grinding efficiency	33
Progress Review 1	39
PART II - Functional Performance Analysis	43
Using the functional performance equation	43
Functional performance efficiency	47
Relating design and operating variables to grinding, classification, and circuit efficiencies	53
Relative accuracy of functional performance parameters	62
Progress Review 2	67
Closing word	77
References	78
Appendix A - Selection of the grindability value to use in functional performance analysis	79
Glossary	81

LIST OF FIGURES AND TABLES

		page
Figure 1.	Elements contributing to the output of a ball mill circuit.	4
Figure 2.	The "effective mill power draw".	6
Figure 3.	The ball mill "specific grinding rate".	8
Figure 4.	The output of a ball mill circuit.	9
Figure 5.	The development of the functional performance equation.	38
Table 1.	Estimates of the accuracy of functional performance parameters.	63

OBJECTIVES

In this module, you will learn how to characterize the performance of ball mill circuits. Specifically, after completing this module, you will be able to:

- List and describe the four elements of the functional performance equation for ball mill circuits.

- Define and calculate the classification system efficiency of a ball mill circuit.

- Define and calculate the grinding efficiency of the ball mill in a ball mill circuit.

- Relate overall ball mill circuit output and circuit efficiency to specific design and operating variables.

- Compare sets of circuit survey data in terms of the elements of the functional performance equation.

The prerequisite module to this one is entitled: "Work Index Efficiency". You will need a calculator to complete this module. The estimated time for completion is two and a half hours including a Progress Review at the end of each Part.

In this module, most terms and expressions included in the Glossary will be identified as such in the Introduction.

INTRODUCTION

In the prerequisite module entitled "Work Index Efficiency", you have learned about *work index analysis** to define overall grinding circuit efficiency. In rod milling, you can use work index analysis to relate design and operating variables to overall circuit efficiency. However, you cannot use work index analysis for the same purpose on ball mill circuits because of the complex interactions between grinding and classification.

In this module, you will learn how to relate design and operating variables to ball mill circuit efficiency through *functional performance analysis**.

This Introduction is seven pages long. It may seem rather lengthy; however, we feel that it is necessary to give you an *overview* of what functional performance analysis is about so that you can more efficiently cover the contents of this module.

Let's get started...

In functional performance analysis, you must differentiate between "coarse" and "fine" particles. To do so, you can select a specific particle size as the target grind size for the ball mill circuit; for example, it is convenient to select the **desired 80% passing size** as the target grind size. You can then use this target grind size to define and distinguish between "coarse" and "fine" particles in any of the given circuit streams.

Coarse particles are therefore *larger than* the circuit target grind size. **Fine particles** are therefore *smaller than* the circuit target grind size.

For any process, including ball mill circuits, we can say that **output** equals *input* multiplied by *efficiency**.

Output = Input x Efficiency

In a ball mill circuit, the "output" can be defined as the **production rate of fines** of the circuit. As for any output, ball mill circuit output is a function of both its inputs and efficiencies.

There are two "inputs" to a ball mill circuit: the **ore** fed to the circuit and the **power** delivered by the grinding mill.

A ball mill circuit has two "efficiencies": that of the *ball mill grinding environment** and that of the *classification system**. A ball mill circuit has two efficiencies because it has two main functions:

- The *grinding* of coarse particles; and,
- The *removal* of the fine particles to make room for grinding more coarse particles in the ball mill.

The *overall* efficiency of the ball mill circuit is therefore comprised of two efficiencies: that of the "ball mill grinding environment" and that of the "classification system".

Note

In functional performance analysis, *classification system efficiency** refers to the fines removal effectiveness of the classification *system* of the circuit - it is not just the efficiency of the classifier (normally viewed as hydrocyclone performance).

Look up "classification system" in the Glossary if you have not already done so.

The output of a ball mill circuit is therefore a function of two inputs and two efficiencies. This is illustrated in Figure 1.

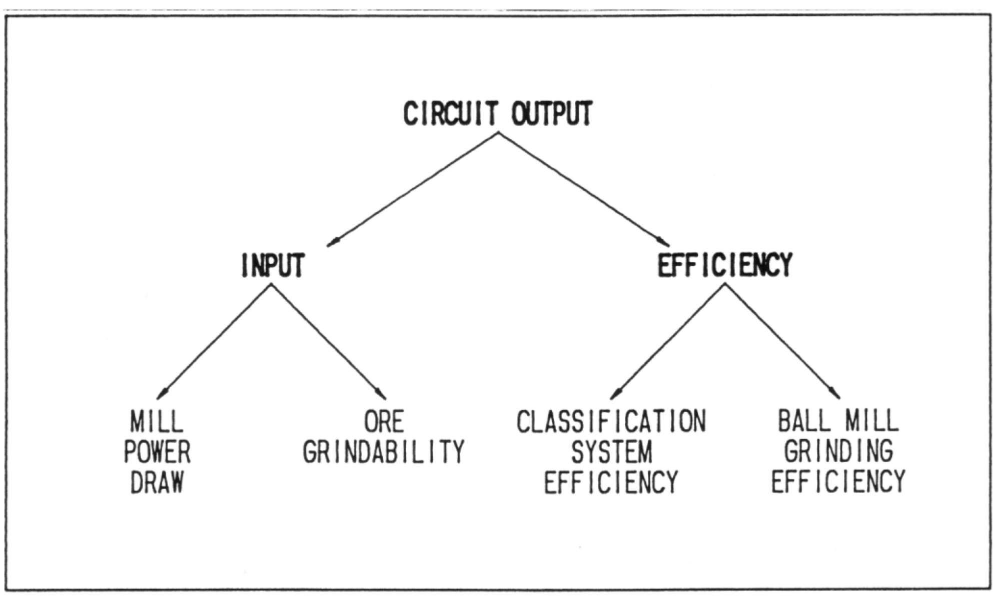

Figure 1. Elements contributing to the output of a ball mill circuit.

Let's look at classification system efficiency.

If a ball mill contained only coarse particles, then 100% of the mill grinding volume and power draw would be applied to the grinding of coarse particles. In reality, the mill always contains fines: these fines are present in the ball mill feed and are produced as the particles pass through the mill.

For example, when 60% of the solids in a ball mill is coarse, then *the coarse solids inventory* * in the mill is 60%, and only 60% of the mill grinding volume and power is used for the grinding of coarse particles. The *classification system efficiency* of the circuit is then only 60%.

We can simply define "classification system efficiency" as the **proportion of coarse solids** to **total solids** in a *ball mill*.

Classification system efficiency (%)	=	Coarse solids inventory in the *ball mill* (%)

Figure 2 illustrates that the **total mill power draw** multiplied by the **classification system efficiency** is the *effective mill power draw **. The effective mill power draw is the power draw that is applied to the grinding of coarse particles.

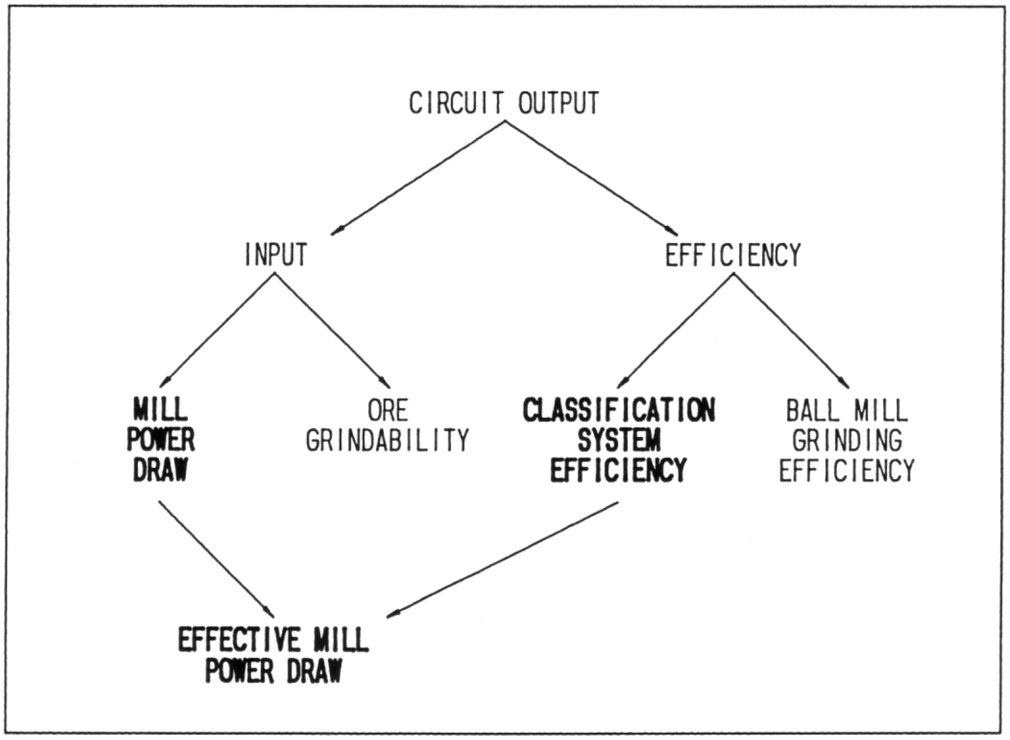

Figure 2. The "effective mill power draw".

Now let's see how the remaining two terms, ore grindability and *ball mill grinding efficiency** in the above figure, come into the picture.

Let's define the *ball mill specific grinding rate** as the weight of new product (fines) produced per unit of *effective energy** (applied to the coarse particles).

$$\text{Ball mill specific grinding rate (t/kwh)} = \frac{\text{Circuit output of fines (t/h)}}{\text{Effective mill power draw (kw)}}$$

We can then define the **grinding efficiency of a ball mill** as the ratio between the specific grinding rate of the coarse solids in the ball mill and the grinding rate (grindability) of the ore in a standard laboratory mill. The grindability characteristic of the ore can be measured in a standardized laboratory test mill.

$$\text{Ball mill grinding efficiency} = \frac{\text{Specific grinding rate of coarse particles (in the plant ball mill)}}{\text{Ore grindability (in the lab ball mill)}}$$

The units of "ball mill grinding efficiency" will be covered in detail in the first part of the module.

Alternatively, we can say that:

$$\text{Specific grinding rate of coarse particles (in the plant ball mill)} = \text{Ball mill grinding efficiency} \times \text{Ore grindability (in the lab mill)}$$

These are the two remaining elements of the four elements that define ball mill circuit output. See Figure 3.

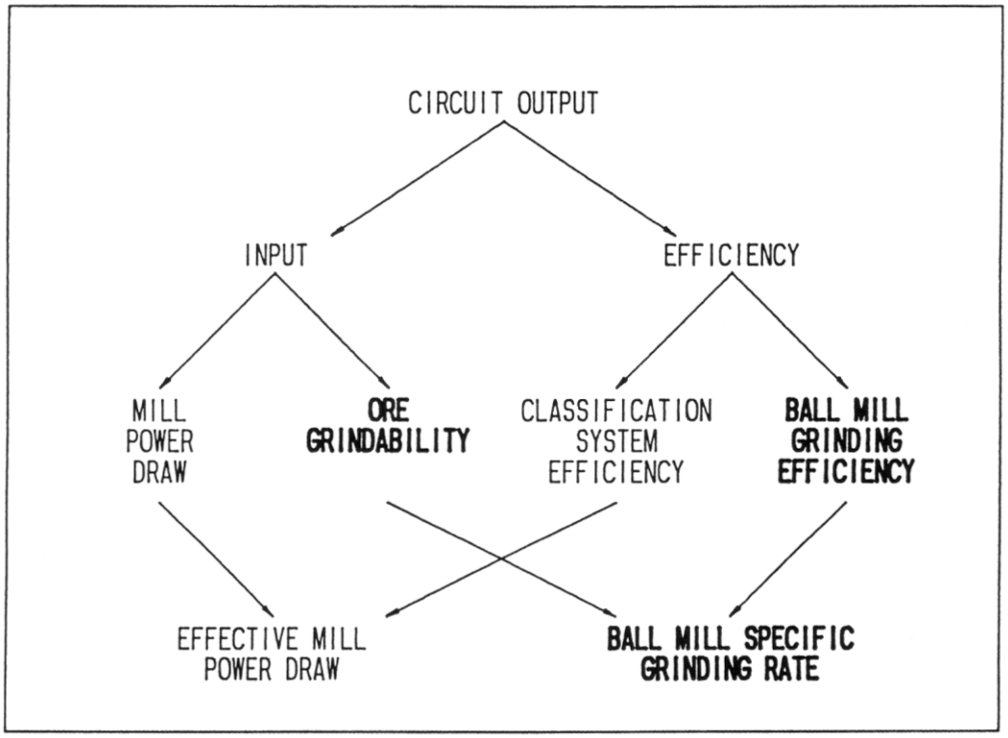

Figure 3. The "ball mill specific grinding rate".

Finally, we can recombine the **effective mill power draw** and the ball mill **specific grinding rate** of coarse particles to once again derive the **circuit output**:

Circuit output of fines (t/h)	=	Effective mill power draw (applied to coarse particles) (kw)	x	Ball mill specific grinding rate (of coarse particles per unit of energy applied to them) (t/kwh)

Study Figure 4.

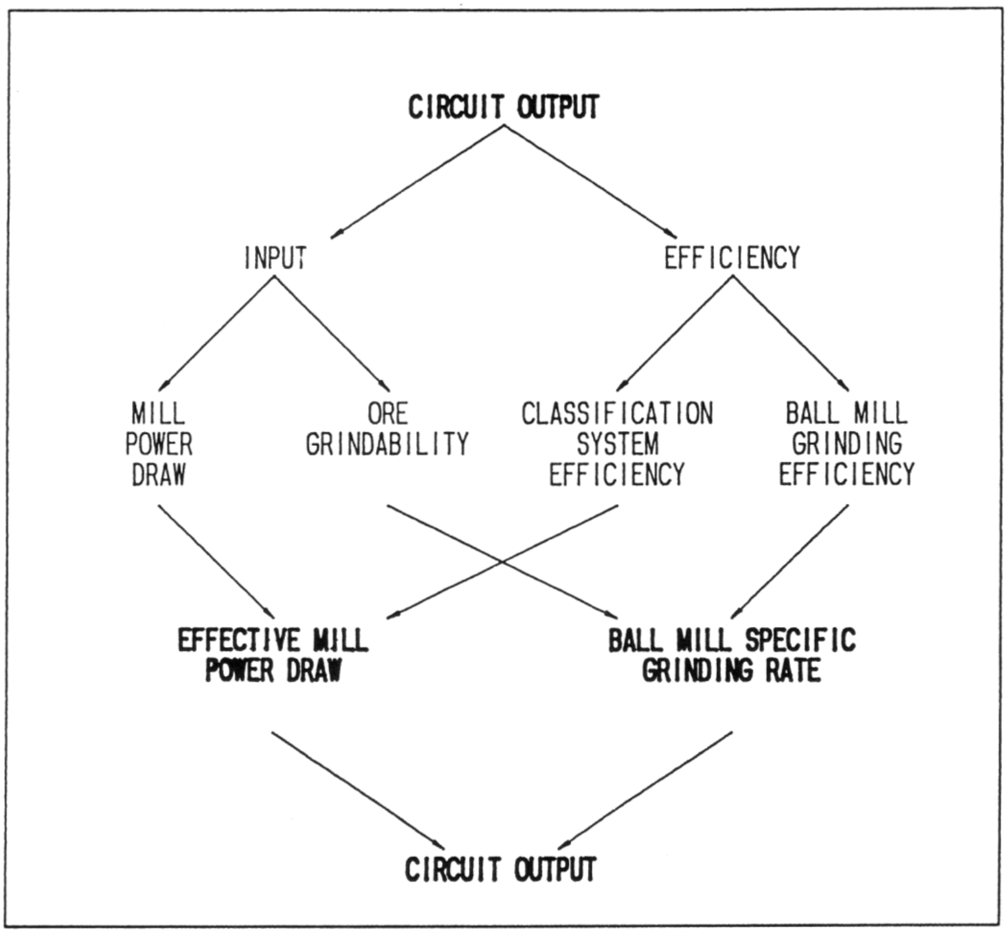

Figure 4. The output of a ball mill circuit.

The equations presented in this introduction can be combined to give the **functional performance equation** for ball milling:

Circuit output	=	Ball mill power draw	x	Classification system efficiency	x	Ore grindability	x	Ball mill grinding efficiency

This concludes the introduction to functional performance analysis for ball mill circuits.

You may wish to take a break at this time. In Part I of this module, you will learn how to evaluate or use each element of the functional performance equation from the operating data and laboratory results from circuit surveys.

PART I - THE ELEMENTS OF THE FUNCTIONAL PERFORMANCE EQUATION

In this part of this module, you will learn how to calculate the following elements of the functional performance equation:

- Circuit output of fines
- Classification system efficiency
- Effective mill power draw
- Ball mill specific grinding rate
- Ball mill grinding efficiency

CIRCUIT OUTPUT OF FINES

The **circuit output** is defined as the **production rate of fines** by the circuit. It is calculated from three values:

1. The dry ore feed rate to the circuit (t/h).
2. The % fines in the circuit feed.
3. The % fines in the circuit product.

Use this equation to solve for circuit output:

$$\text{Circuit output (t/h)} = \left(\text{Fines in the circuit product (fraction)} - \text{Fines in the circuit feed (fraction)} \right) \times \text{Circuit ore feed rate (t/h)}$$

Use this equation in the following two exercises.

Exercise

During Survey #1 at the Camco Mine, the ore feed rate to the ball mill circuit was 67 t/h. The circuit feed contained 29.33% of -106 micron (150 mesh) material (fines) and the circuit product contained 78.54% of -106 micron (150 mesh) material.

What was the circuit output of fines during the survey?

The answer follows.

Answer

33.0 t/h = (0.7854 - 0.2933) x 67 t/h

The circuit was therefore producing 33.0 t/h of fines during Survey #1.

Solve the second exercise.

Exercise

During a second survey of the same circuit, the ore feed rate was 70 t/h. The feed to the ball mill circuit contained 30.38% fines and the circuit product contained 77.60% fines.

What was the circuit output of fines during the second survey?

The answer follows.

Answer

33.1 t/h = (0.7760 - 0.3038) x 70 t/h

The circuit was therefore producing 33.1 t/h of fines during Survey #2.

Next, let's see how to determine the "classification system efficiency" of a grinding circuit.