In section 4.4.4.1 it was shown that the flow of material down the length of the mill is given by:

$$ \text{Flow} = (Z)(J)(dh/dx) $$

For a continuous system we can write:

$$ \text{Flow}(x,t) = (Z)(J(x,t))(\frac{dh(x,t)}{dx}) $$

where:

- $h(x,t) = \text{height of the mill charge at point } x \text{ along the mill and at time } t$
- $Z = \text{a constant}$
- $J(x,t) = \text{width of the charge surface at point } x \text{ along the mill and at time } t$

Assume that $J(x,t)$ is a constant in the region of operation (i.e. where $\sigma$ is small), and, since the sign of
\[ \frac{dh}{dx} \text{ is negative, to ensure that the overall flow is positive the overall flow equation must be:} \]

\[ \text{Flow}(x, t) = -Z'(\frac{\partial h(x, t)}{\partial x}) \]

where:

\[ Z' = (Z)(J(x, t)) \]

now

\[ \frac{dm(x, t)}{dt} = \frac{\partial \rho A(x, t) \Delta x}{\partial t} = \text{Flow}(x, t) - \text{Flow}(x + \Delta x, t) \ldots A2.0 \]

where:

\[ \frac{dm(x, t)}{dt} \text{ rate of change of mass at a point } x \text{ along the mill and at time } t \]

\[ A(x, t) = \text{cross-sectional area of the charge at point } x \text{ along the mill at time } t \]

\[ \rho = \text{density of mill charge} \]

A2.0 can be rewritten as:

\[ \frac{\partial \rho A(x, t)}{\partial t} = \frac{\text{Flow}(x, t) - \text{Flow}(x + \Delta x, t)}{\Delta x} \]

or

\[ \frac{\partial \rho A(x, t)}{\partial t} = \frac{\partial \text{Flow}(x, t)}{\partial x} = \frac{\partial h(x, t)}{\partial x} \]

but \( J(x, t) \) has been assumed constant, therefore the above equation becomes:

\[ \frac{\partial A(x, t)}{\partial t} = Z' \left( \frac{\partial^2 h(x, t)}{\partial x^2} \right) \ldots \ldots \ldots \ldots \ldots A2.1 \]

Assuming that \( \sin \Theta = \Theta \) for values of \( \Theta \) in the operating region, (see Appendix 3 for an error analysis of this), it can be shown that:

\[ h(x, t) = r + r_0(x, t) \ldots \ldots \ldots \ldots \ldots A2.2 \]

\[ A(x, t) = \frac{1}{2} \pi r^2 + 2r^2 \Theta(x, t) \ldots \ldots \ldots \ldots \ldots A2.3 \]

Substituting A2.2 and A2.3 in A2.1, the following equation results:

\[ 2r \frac{\partial^2 \Theta(x, t)}{\partial t} = \frac{Z' \rho r^2 \Theta(x, t)}{\rho} \]

\[ \frac{\partial^2 \Theta(x, t)}{\partial x^2} \]
Assumption 1:

\[ J(h_p - h_q) = A_p - A_q \]

(for the mill approximately one half full)

Consider the above figure. The error of the assumption is due to the fact that the shaded regions are not included in the area calculation.

It can be shown that when the mill mass varies by 15% about the one half full point:

\[ J = 0.993r \quad (0.7\% \text{ error}) \]

Therefore, in this case, the maximum error in area will be 1.4%.

In the case of a 30% variation about the one half full...
point:

\[ \frac{J}{r} = 0.971r \]

resulting in a 6% error in area.

**Assumption 2:**

\[ \sin \theta = \theta \text{ in the operating region of the mill.} \]

A 15% mill mass fluctuation means that \( \theta \) is 6.8°. This results in a 0.3% difference between \( \theta \) and \( \sin \theta \).

A 30% mill mass fluctuation means that \( \theta \) is 13.8°. This results in a 1% difference between \( \theta \) and \( \sin \theta \).
APPENDIX 4

DERIVATION OF BULK DENSITY FUNCTION

bulk density

\[ \text{bulk density} = \frac{\text{total mass}}{\text{total volume occupied}} \]

\[ \text{total mass} = MM + X_j + X_2 \]

\[ \text{total volume occupied (assuming 4% voids)} = 1.4 \left( \frac{MM}{W} \right) \]

Therefore:

\[ \text{bulk density} = \frac{W}{1.4 + \frac{W(X_j + X_2)}{1.4 (MM)}} \]
APPENDIX E

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